ACID RAIN: A TECHNICAL INQUIRY

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ACID RAIN: A TECHNICAL INQUIRY

TUESDAY, MAY 25, 1982

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
Washington, D.C.

The committee met at 10:05 a.m., in room 4200, Dirksen Senate Office Building, Hon. Robert Stafford (chairman of the full committee) presiding.

Present: Senators Stafford, Domenici, Chafee, Abdnor, Randolph, Moynihan, Mitchell, and Baucus.

OPENING STATEMENT OF HON. ROBERT T. STAFFORD, U.S. SENATOR FROM THE STATE OF VERMONT

Senator STAFFORD. The Committee on Environment and Public Works will please come to order.

For the committee, I am happy to welcome all of our guests. We are happy that the panel is appearing here to assist us in further understanding the problems of acid rain.

This is a particularly difficult morning for Senators. This Senator has already testified in front of the Appropriations Committee and I have also been present and voted on one major piece of legislation in the Labor and Human Resources Committee, and delivered a short speech on the Peace Academy, which is the second item of business in front of that committee, and left Jennings Randolph, the ranking member of this committee, to move forward with the Peace Academy for both of us and others interested in it. So gradually I can account for where my committee members are, and they are all busy and will get in here when they can. I want the panel to know and the people who are here to know that what is said here this morning will be studied by all of the members of this committee and by staff people representing them.

Today and Thursday we will conduct two additional technical inquiries into the subject of acid rain. The committee has already conducted previous hearings on this particular subject. In addition to the scientific inquiries of this week, I am instructing the staff to review and analyze the various studies of the costs of an acid rain control program. Based on this analysis, I will determine whether a hearing is necessary or desirable.

The subject of today's inquiry is the atmosphere chemistry and meteorology. Thursday's hearing will deal with the effects of acid rain. It is unfortunate that the schedules of our witnesses did not permit the order of the two hearings to be reversed.

Acid rain, as with virtually every other issue in environmental matters, is a case in which policymakers must deal with a certain degree of scientific uncertainty. That uncertainty must be weighed against the risks associated with inaction. In this respect, acid rain is no different than many other issues which this committee has confronted in the past and no doubt will continue to confront in the future.

In such cases of uncertainty, the risk which is being taken is highly relevant to the weight which should be assigned to the scientific uncertainties. In the case of acid rain, the risk is quite literally the economy of an entire region, a major region of the United States. For each of the members there is an article which appeared in this Sunday's edition of the Boston Globe. It describes the death in the State of Vermont, my State, of 50 percent of our red spruce population. Red spruce is a highly economically important industry that should live for 300 to 400 years. There are two possible explanations for the death of these red spruce. One is an as yet undiscovered root disease, and the other is acid rain. Similarly, in the case of dead and dying streams and lakes, there are two possible hypotheses, may I suggest, and one of these is acid rain. Time and again when we discuss crop losses, forest damage, dead lakes, or any one of the several other losses, acid rain is one of the two or three possible solutions. Often it appears to be the only reasonable explanation.

From Vermont's perspective, the magnitude of the risk is Vermont itself. Today's hearing, therefore, will help us decide what the appropriate action is in view of the uncertainty, if any, which exists.

But the existence of scientific uncertainty is not, and never has been, in the judgment of this Senator, an adequate reason for complete inaction. That is particularly true in a case like this in which the values at risk are so great.

As we hear from today's witnesses, I hope we will be directed toward a responsible solution to the problem rather than an intolerable policy of inaction. I also hope that each of the panelists will, if at all possible, restrict himself to no more than 5 minutes so there will be adequate time for questions. Of course, the Chair will note now that where statements have been prepared and considerable effort has been put forward to do that, that they will be placed in the record in full as if delivered.

I am happy to see that Senator Mitchell of Maine, a most valuable member of this committee, has arrived. I would invite him to make any opening statement he may have.

OPENING STATEMENT OF HON. GEORGE J. MITCHELL, U.S. SENATOR FROM THE STATE OF MAINE

Senator MITCHELL. Thank you very much, Mr. Chairman.

As members of this committee and others present know, I proposed legislation to deal with the problem of acid rain last year. I did so only after I had carefully examined the evidence on all sides of the issue. I did so only after I became convinced that the environmental consequences of inaction were not acceptable.

The process of examination we undertake this morning is a continuation of the process through which I arrived at the conclusion that legislative action must be taken now, not at some indefinite time in the future. We will hear differing points of view expressed today. We will hear uncertainties expressed. We will receive divergent and conflicting recommendations. We should expect no less. There are no easy answers to the problem of acid rain, just as there was no easy answer when the Congress considered the Clean Air Act of 1970 and just as there were no easy answers when all of the other environmental statutes enacted in the last decade were passed. The conduct of human affairs in general and environmental issues in particular do not often lend themselves to simple, self-evident solutions. In most cases we cannot avoid making a balancing judgment.

With respect to the issue of acid rain, I have made that judgment. I have weighed the magnitude of the risk of inaction to our natural resources against the uncertainties in our knowledge. In my view, we as policymakers must act now. I am hopeful that my colleagues here and in the full Senate will reach the same conclusion.

I look forward, Mr. Chairman, to the testimony of all of the distinguished witnesses today. I know that their statements will contribute to our understanding of the problem. Thank you, Mr. Chairman.

Senator **Stafford**. Thank you very much, Senator Mitchell.

If agreeable to the committee, and I think it will be, and to our witnesses, the Chair would suggest we go in alphabetical order, and that means that Dr. Barrie, who is a research scientist, Atmospheric Environment Service, Atmospheric Dispersion Division, Downsview, Ontario, will be the first witness.

I am glad the table is wide enough so you could squeeze in, Dr. Barrie.

STATEMENTS OF L. A. BARRIE, RESEARCH SCIENTIST, ATMOSPHERIC ENVIRONMENT SERVICE, ATMOSPHERIC DISPERSION DIVISION, DOWNSVIEW, ONTARIO; KENNETH L. DEMERJIAN, DIRECTOR, METEOROLOGY AND ASSESSMENT DIVISION, ENVIRONMENTAL SCIENCES RESEARCH LABORATORY, ENVIRONMENTAL PROTECTION AGENCY, RESEARCH TRIANGLE PARK, NORTH CAROLINA; ROY R. GOULD, HARVARD SCHOOL OF PUBLIC HEALTH, BOSTON, MASS.; BRUCE HICKS, ATMOSPHERE TURBULENCE AND DIFFUSION LABORATORY, OAK RIDGE, TENN.; JOHN R. HOLMES, CHIEF, RESEARCH DIVISION, CALIFORNIA AIR RESOURCES BOARD, SACRAMENTO, CALIF.; VOLKER MOHNEN, DIRECTOR, ATMOSPHERIC SCIENCE AND RESEARCH CENTER, ALBANY, N.Y.; MICHAEL OPPENHEIMER, SENIOR SCIENTIST, ENVIRONMENTAL DEFENSE FUND, NEW YORK, N.Y.; KENNETH RAHN, ASSOCIATE RESEARCH PROFESSOR, GRADUATE SCHOOL OF OCEANOGRAPHY, UNIVERSITY OF RHODE ISLAND, NARRAGANSETT, R.I.; AND JACK SHANNON, ARGONNE NATIONAL LABORATORY, ARGONNE, ILL.

Dr. **Barrie**. Thank you, Mr. Chairman.

I would like to emphasize at the outset that I was invited here as a scientist and not a representative of the Canadian Government.

It is fairly well understood now that the major source of acidity in rain is the oxides of sulfur and nitrogen, so I will focus on those substances in my short summary.

The long-range transport of these substances is fairly well documented. On the short spatial scale, mass budget studies that I and others have done around isolated point sources show that over 95 percent of the pollutants being emitted are being transported beyond a 100 kilometers of the source. Where they go beyond the 100 kilometers is a big question, the key one here. The way we set about to answer this is with the use of long-range transport models, coupled with measurements of precipitation chemistry made in the eastern half of North America.

In the United States-Canada Memorandum of Intent negotiations that are now proceeding, there is a modeling working group that is testing or comparing different models—three Canadian and five American. One of the models is represented here by Dr. Shannon. All of the models agree on two major features of the transport problem. That is, first of all, that the total annual sulfur deposition in any New England State is comprised of small contributions from many States. The second one is that the total annual sulfur deposition in the Adirondacks and northern New England is broken up as follows:

Thirty-five to fifty percent of the annual deposition originates from the Midwest, Pennsylvania, and New York, with each of those areas contributing about the same amount, 10 to 15 percent. Twenty to forty percent comes from Canada.

It is my opinion that this evidence strongly indicates that the only way to alleviate the problem of acid rain deposition in eastern North America is to control emissions in all States and provinces.

I would like to address an issue raised by Dr. Ken Rahn concerning the scale of transport of acidic precursors. Dr. Rahn uses a manganese-to-vanadium ratio to trace particles in the atmosphere. It does not apply to gases. It is also very well known that two-thirds of the acidity in precipitation comes from gases, for which the manganese-to-vanadium technique is not an adequate surrogate. One reason for this is acidic gases are emitted or released into the atmosphere at different heights than the bulk of particulates are and are therefore transported in different ways.

On the issue of emissions control, Dr. Mohnen has raised the question of the deposition in the Northeast not responding to a reduction or even an increase in emissions because of saturation. I would like to emphasize that Dr. Mohnen's theory is simply a theory and as yet unproven.

It also focuses mainly on wet deposition. We know that dry deposition—that is, the interaction of pollutants directly with the Earth's surface—is a major component of the total acid deposited. Fifty to seventy percent of the total acidic deposition is dry in areas near the sources and immediately downwind of sources, that is, such areas as the Midwest and Pennsylvania. Twenty to thirty percent of the deposition in New England is dry. There is no complicating chemistry between the emission and the deposition of sulfur dioxide gas in the dry form. So we can definitely say that a reduction in emissions will bring about a reduction in deposition.

It is also my opinion that a reduction in emissions of 50 percent will bring about a reduction in total deposition of 30 to 65 percent.

Finally, I would like to say a word about nitrogen oxides. In the Northeast, nitrogen oxides are responsible for 20 to 30 percent of the acidity of precipitation. Now, our freshwater lake biologists tell us that the acidity related to nitrates is neutralized when the nitrate ion is digested by aquatic biota and that therefore the threat to our lakes is mainly sulfur emissions. But if there are environmental effects due to nitrate-related acidity, it is important that we consider them in an emissions control strategy.

Thank you.

Senator Stafford. Thank you very much, Dr. Barrie. We especially appreciate the brevity with which you have been able to make some strong points. That always appeals to somebody from Vermont.

The next witness will be Dr. Kenneth L. Demerjian, Director of the Meteorology and Assessment Division, Environmental Sciences Research Laboratory, Environmental Protection Agency, Research Triangle Park, N.C. Dr. Demerjian.

STATEMENT OF KENNETH L. DEMERJIAN

Dr. Demerjian. Thank you, Mr. Chairman. I have prepared testimony which has been submitted for the record. I thought for the sake of time and brevity that I would more or less give an overview of what is in that testimony.

Generally, the Meteorology and Assessment Division of the Environmental Sciences Research Laboratory is responsible for doing research and development in process-related as well as modeling simulation for the Environmental Protection Agency. We have a history of over 10 to 15 years worth of research in the modeling of atmospheric species, and within the area of acid deposition we have started a program which is underway since 1979.

One point that should be made is that this research obviously is catapulting off a lot of activities that have gone on within the agency for studying other pollutant species within the atmosphere.

My written testimony more or less gives three major areas: the history of the atmospheric processes research program within the agency, highlights of major research efforts in the next 3 to 5 years that will be going on in acid rain and is part of the national acid precipitation assessment plan, the interagency task force, and an example of some representative work.

What I would like to highlight is the fact that there are several outstanding issues in acid precipitation modeling and that our research program has been designed and developed around trying to address these issues in the next 3 to 5 years.

Within that activity, there are four areas associated with precursors to acid deposition. Here we would like to determine for different meteorological conditions whether sulfur dioxide or oxidants have a limiting component in atmospheric reactions to produce acid sulfates. As many of you are probably aware, many of the models that have been tested, or actually all of the models that have been tested under the United States-Canada MOI are models which assume linear transformations of the sulfur oxides to sulfates. There is considerable information now available that would indicate that this process is nonlinear, that the chemical reaction for transforming SO_2 to sulfates is a process that is not directly associated with SO_2 on a 1-to-1 basis.

Senator **Chafee**. Could I ask a question here, Mr. Chairman? I don't know what linear means.

Dr. **Demerjian**. I am sorry. The term linear means that for every effective reduction of SO_2 molecule, one sees the effect in a reduction in sulfate molecule produced. It is possible or the indication is that if it is having a nonlinear process, that relationship could be other than 1-to-1. You could have potentially two times more reduction for every one, or potentially two times less reduction of the acid-forming substance for the reduction of the reactant. So it is conceivable that, for example, one would implement the strategy for reducing sulfur and see no effect, if the nonlinearities are extensive enough.

That is a fundamental issue that many of us are concerned about with using these tools for assessment.

The program within EPA has been designed to try to get a better handle and expand and elucidate our understanding of these fundamental processes and to assure they are treated properly within the models.

Senator **Stafford**. Let me understand you, too, before you go further. Do I understand that in the process of converting from SO_2 to sulfates you are saying that you don't know whether a molecule of SO_2 creates twice as much sulfate or half as much sulfate as the original sulfur oxide? Is that what you said?

Dr. **Demerjian**. That is generally correct, yes. What the models assume right now is that the relationship is one-to-one, that for every molecule of SO_2 we transform, that rate is linear and it is a one-to-one relationship. It turns out that the chemistry of the problem is such that we understand that there are fundamental processes by which this transformation takes place. But because of the complexities of it and the nature of the precursors that are involved, we are concerned that the linearization that has been used in these models gives a false feeling for the impact of control versus the effect that you plan to see in the atmosphere. So that much of our process research is directed to the chemistry of SO_2 transformations, both in the gas phase and in the wet phas; heterogenous processes, droplets, et cetera.

Another area of our program involves the conversion of NO_2 to nitrate and the deposition of nitrates, which appear to be faster than the similar processes with sulfur compounds. The relative importance of sulfur to nitrogen deposition as a function of distance from the source region must be quantified. There will be major efforts in that particular area.

We would like to determine under what atmospheric conditions neutralizing agents, such as windblown alkaline dust or ammonia, will affect the acidity of deposition.

There is a whole area regarding local sources and their contribution to the total acidic problem. We would like to conduct field studies to provide a data base for the validation of existing mesoscale models which will be used to determine under what meteorological conditions local sources dominate the acid deposition problem.

Cogent to many of these activities in the process area is the source-receptor relationship. Conducting major field studies to provide the first available data base on long-distance trajectories which will be used for source-receptor model validation and trajectory forecasting. Obviously these models have various components in terms of their being able to do the job that they are supposed to do, which is understanding the relationship between source emissions and receptors.

There are three major components in order to understand that process. One is the process of transport, the actual movement of the air mass from one place to another. The other is the chemical transformation processes that go on within that air mass as it is transported. The third is the major removal mechanisms by which that air is either cleansed, depending on how you look at it. Those are both by dry and wet removal.

These three components have to be evaluated and tested, and we must have a better handle on the uncertainty of our ability to predict these kinds of transport and transformation fields.

We would like to develop and incorporate the nonlinear chemistry for sulfur, nitrogen, and volatile organic compounds and the meteorology of horizontal and vertical transport; improve one or more of the existing simpler trajectory type models by adding improved parameterization of the nonlinear chemistry and transport which will be derived and validated from the more precise grid-type models. All of the models, except for one within the United States-Canadian activity was a trajectory-type model, we would like to see the linearization of those, the chemistry in those models at least applied to the nonlinear process.

The most critical feature is quantifying the inherent uncertainties in the models in terms of their ability to forecast source-receptor relationships for control strategy evaluation purposes.

Right now we have a situation where the margin of uncertainty, in my opinion, is intolerable. Virtually we have a situation here it is very difficult for me to tell you that if you control 50 percent SO_2, whether you will see in effect any place downwind, depending on the complexities of this nonlinear process——

Senator **Chafee**. Could you repeat that statement again, please?

Dr. **Demerjian**. I think currently the position that we have is there is significant uncertainty in this chemical transformation process that there are situations where in particular areas, if you reduced SO_2 by 50 percent, I think it is possible that you would see no impact in the reduction of sulfates.

Senator **Mitchell**. You are speaking in behalf of the administration and the EPA?

Dr. **Demerjian**. I am speaking based on my scientific opinion and my understanding of the transformation processes.

Senator **Mitchell**. Is that the position of the administration and the EPA?

Dr. **Demerjian**. I am really not sure what the position of the administration is on that particular matter.

Senator **Mitchell**. You are not sure what the position of the Reagan administration is on the acid rain legislation?

Dr. **Demerjian**. I think their position is that there is uncertainty.

Senator **Mitchell**. That is one area where there is no uncertainty, Doctor.

Dr. **Demerjian**. My understanding is that the position is that there are significant uncertainty in the science which would potentially mean that action shouldn't be taken now.

What I am trying to tell you, as a scientist, I can tell you what particular areas definitely need some elucidation before we are going to be able to answer these questions. My feeling is that a policymaker can make a decision given any level of uncertainty if he is willing to take into consideration the risk and the impacts. And I feel that we as scientists can tell you what that level of uncertainty is. We can't tell you what is the final decision in terms of your policy.

Senator **Stafford**. Doctor, I gather from what you are saying that you and the preceding witness, Dr. Barrie, disagree on the uncertainty involved in the models that you have been testifying to.

Dr. **Demerjian**. We have had a chance to discuss it considerably since we are both members of the Canadian working group. I believe that there is some difference of opinion.

Senator **Chafee**. I don't think it is just believe. There is.

Dr. **Demerjian**. If the time presents itself, we could certainly discuss this issue in terms of the scientific implications of what it is that I am saying about the transformation processes, as we understand them now, and the direction that our program is going in terms of trying to elucidate those.

Senator **Stafford**. Doctor, could you summarize whatever else you wish to say? We have now consumed 10 minutes.

Dr. **Demerjian**. Fine; generally the only other three areas I would like to highlight is the fact that EPA also has underway programs to look at the spatial and temporal variations in acidic depositions. These are to provide annual reports on the spatial and temporal variability of wet deposition from monitoring networks, to upgrade the methodologies for monitoring wet deposition by providing instrumentation for real-time measurement of pH and selected anions and cations, as well as to install a network for monitoring dry deposition using the best available methodology which will exist in approximately 3 to 5 years.

One of the very substantial issues in validating the existing models is the fact that, as you have heard, 50 percent of the amount of pollutants in the atmosphere are dry deposited; yet, presently this country does not have the technique for measuring this dry deposition. So you can virtually say that there is one whole half of these models that we will have no way of evaluating. Therefore, it is very important that we start to get a handle on dry deposition to give us a much firmer understanding of how these models perform.

I believe the bottom line to this problem is scientific credibility. Unless that underlies the policies and positions that we take, I feel that we will always be opening ourselves up to criticism in any actions we take, and rightfully so. Thank you.

Senator **Stafford**. Thank you, Dr. Demerjian.

Dr. Roy Gould, Harvard School of Public Health, Boston, Mass. Dr. Gould.

STATEMENT OF ROY GOULD

Dr. GOULD. Thank you, Mr. Chairman, members of the committee. My name is Roy Gould. I hold a Ph. D. degree in biophysics from Harvard University and I am currently a research fellow at the Harvard School of Public Health and the Harvard Center for Earth and Planetary Physics.

I would like to briefly address two questions. First, where does the sulfur, which we have already heard this morning from Dr. Barrie, is the chief contributor to acid deposition in the Northeast, where does that sulfur come from? And second, would a reduction in sulfur emissions reduce acid deposition?

There is a very large body of evidence that collectively answers the first question, but I want to cite just one particularly important and illustrative study, the multistate atmospheric pollution power production study. I will limit my comments to the role of sulfate since sulfate, or sulfuric acid, is the chief contributor to the acidity of precipitation in the Northeast. The measurements I want to describe come from a monitoring station in the Adirondacks, which we all know is of special interest because the Adirondacks are particularly vulnerable to acid deposition.

The monitoring station measured the sulfate content of each rainfall and snowfall in the Adirondacks during the year 1978. In addition, the direction, or sector, from which the air masses bringing the storm came was determined by a technique known as trajectory analysis. Together, these measurements allow one to determine how much sulfate pollution comes from each sector to the Adirondacks. These data have been presented by Wilson, Mohnen and Kadlecek, and so far as I know, the data themselves have not been questioned by anyone.

Let me summarize those measurements for you. They show, first of all, that the level of sulfur pollution in rain and snow depends strongly on the direction that the precipitation comes from. Precipitation from the Midwest sector contains the highest concentrations of sulfate. Precipitation coming from the sector of Canada that includes Sudbury also contains high levels of sulfate. Precipitation that comes from the remaining sectors, which include eastern Canada and all of New England, contains only about a quarter as much sulfate as precipitation coming from the Midwest.

Now, the amount of sulfate that actually falls on the Adirondacks obviously depends not just on how polluted the rain is but how much rain falls. Unfortunately, most of the precipitation that comes down in the Adirondacks comes from the Midwest sector. A fair amount also comes from the Canadian sector. This, of course, simply reflects the fact the prevailing winds blow from west to east.

The total amount of sulfate that comes down, and the acidity it represents—that is really the bottom line because that is what is harmful to the environment—the total amount depends on the two factors I have just cited—how polluted the rain is and how much rain comes down. What is that bottom line? About two-thirds of the sulfate comes from the Midwest. Roughly a quarter of the sulfate that falls in the Adirondacks comes from the Sudbury sector. The remaining sectors, which include eastern Canada and all of New England, contribute only a few percent of the total. In fact, all of New England contributes less than 5 percent of the sulfate that falls on the Adirondacks.

Finally, let me emphasize that sulfate in rain is just one form of acid deposition. It is really just the tip of the sulfur iceberg. There are other forms of sulfur deposition, as we have already heard this morning—for example, sulfur dioxide, which comes down either dissolved in rain or when it is not raining, which is 90 percent of the time. That sulfur dioxide also contributes acidity to the environment because that sulfur dioxide can be converted to sulfuric acid after it comes down. Sulfate in rain, of course, is just the most convenient form of sulfur for us as scientists to measure.

Since all the sulfur that goes up must come down, and since all of that sulfur must ultimately contribute to acid deposition, reducing sulfur emissions will necessarily reduce acid deposition. Thank you.

Senator STAFFORD. Thank you very much, Dr. Gould.

The next witness will be Mr. Bruce Hicks of the Atmosphere Turbulence and Diffusion Laboratory.

I was about to note that atmospheric turbulence is something we Senators have become accustomed to lately in our debates in the Senate. As far as I know, nobody has made any scientific study of it. [Laughter.]

Mr. Hicks, we welcome your testimony.

STATEMENT OF BRUCE HICKS

Mr. HICKS. Thank you, Mr. Chairman. I don't wish to go into the detail of the written testimony. Instead, I would like to address areas where we have uncertainty with the models that are being used at the moment. I would like to emphasize how much of that uncertainty is being resolved as the process of scientific investigation is proceeding.

Over the last 10 years, the models have improved immensely. We are accustomed to dealing with two kinds of models. One is used on the short range to look at the effects of emissions nearfield, downwind of some source. The model is simple and works well because we can assume the meteorology to be constant. We are then talking about a couple of hours of transport.

At the other extreme, we are talking about global scale models. We know very well that these models work quite well, too. Why? Because they are averaging over the meteorology. It is the intermediate range where we have troubles, with transport over a couple of days, because we can no longer average over the meteorology. The changing conditions will often dominate what is going to happen.

We now know that we can address a lot of these factors in several different ways. We can address them statistically. We cannot yet hope to predict what the effect of a specific occurrence is going to be on a specific occasion. To do so would be to ask questions that are a problem for a weather forecaster. However, we can address average conditions very well.

There are some more uncertainties. One uncertainty concerns the processes of subcloud and incloud scavenging. Subcloud scavenging is the process which occurs when precipitation drops through a powerplant plume and the water gets contaminated accordingly But if we are concerned with regional scale precipitation, quality, we need to be concerned about cloud systems which are inhaling air. They are taking air out of a mixed layer, they are processing that air and changing its chemical characteristics, and they are concentrating material in the rain and then depositing it.

In-cloud processes are doubly important. First, they provide a mechanism to concentrate material in rain. The second factor is that not all clouds rain. I view clouds as immense natural chemical factories which are processing pollutants.

Clouds that do not rain provide natural mechanisms for pollutants to be transformed in the air, and for the resulting products to be transported for long distances in a higher layer of the atmosphere.

Several years ago we knew nothing about such mechanisms. This is one of the instances where scientific research is being productive, and we are starting to learn what is going on.

I would like to discuss dry deposition briefly. It is sometimes said that we cannot measure dry deposition. This statement is quite misleading. It is true that we cannot monitor dry deposition using any of the techniques that are presently available. However, we can measure it in intense case studies of specific pollutants in some circumstances. The results of these case studies can then be used in models to assess dry deposition. The net result is that our understanding of dry deposition is also getting to a stage where we are starting to see the light at the end of the tunnel.

Finally, I would like to point out that whether we are talking about wet deposition or dry, the amount that comes out of the air is a function of how much was in the air in the first place. On the average, it is true then that a reduction in emission rates will affect concentrations in the air, which will then affect the concentrations that are in the material being deposited.

But this is true only on the average, and we could never say that the statement will be verified by a particular experiment in a particular circumstance.

Thank you, Mr. Chairman.

Senator **Stafford**. Thank you very much, Mr. Hicks.

The next witness will be Dr. John R. Holmes, chief of the Research Division, California Air Resources Board, Sacramento, Calif. Dr. Holmes.

STATEMENT OF JOHN R. HOLMES

Dr. **Holmes**. Thank you, Mr. Chairman, members of the committee. I am very pleased to be here as the only representative of the western two-thirds of the country.

For the record, my name is John Holmes. I am director of research for the California Air Resources Board. I am a chemist and have been professionally active in the field of atmospheric chemistry since 1969. A substantial portion of the research program I direct has been devoted to laboratory and field studies of the transport and transformation of air pollutants within the borders of our State.

When I appeared before this committee last October, I described the results of our research on acid rain in California in some detail. I don't think I need to repeat those findings here today. But by way of an update, some additional work has been done by Caltech scientists this winter and during the spring. This work has confirmed our earlier results, that rain in the Los Angeles area is strongly acidic and that nitrogen oxides, rather than sulfur dioxide, are the principal cause of the acidity.

Now, in addition, Professor Hoffman and his colleagues at Caltech have found that fog and stratus clouds in Los Angeles have pH readings as low as 2.2. This is four times more acidic than the most acidic rain samples we have. It is nearly 3,000 times more acidic than unpolluted fog. So at this pH, we expect that fog will cause rapid corrosion of steel and other construction materials. It irritates the eyes, nose and throat. I am going to give the staff a report that has some further details on this work for the committee's use.

Senator **Stafford**. We will place that in the record. [See p. 133.]

In California, the Governor, the Air Resources Board and concerned legislators are determined to prevent the kind of environmental damage that has occurred in the Northeast as a result of acid rain. A bill that would authorize our Board to carry out an accelerated research program and establish additional regulations, as necessary, to limit acid deposition is now moving through the State legislature.

Senator **Chafee**. What would those additional regulations be, Doctor?

Dr. **Holmes**. Controls on NO_x and sulfur dioxide from a variety of sources.

Senator **Chafee**. You mean mobile emissions?

Dr. **Holmes**. Both mobile sources and stationary sources. We have a very stringent control program now, as you know.

Senator **Mitchell**. What would they do, for instance, in stationary sources with sulfur emissions?

Dr. **Holmes**. A number of things that we are doing now and could do more of are desulfurization of fuel oils, of diesel oil, and gasoline; There are regulations on the books now that do this. Controls of NO_x from stationary sources have really only begun to come under consideration. We are moving ahead in that area, too.

Senator **Chafee**. Thank you.

Dr. **Holmes**. Today I want to address some of the specific questions that the committee has been concerned about.

First, what is the probability that substantial reductions in the emissions of acid precursors will lead to correspondingly large reductions in acid deposition? My short answer on that is yes, the probability is very high that they will.

By way of experience from California, we have had an ambient air quality standard for sulfates and sulfuric acid for several years, so we measure sulfates in the atmosphere routinely. In Los Angeles, we also keep a daily record of sulfur emissions from major sources. These records go back into the sixties.

Now, our experience has been that atmospheric sulfate readings have tracked changes in sulfur emissions very closely over the years. And the changes in emissions have been substantial because the fuel supply has shifted between high-sulfur fuel oil, low-sulfur fuel oil, and natural gas.

On the other hand, daily sulfate measurements do not correlate well with daily sulfur emissions. In other words, the system does have this nonlinear aspect. This is because variations in meteorological factors and oxidation rates are much larger than the short-term fluctuations in SO_2 emissions.

But I think you have to look at it this way: Protecting the environment from the ravages of acid rain is largely a matter of limiting the seasonal and long-term delivery of acidic sulfates to distant receptor sites. So I am convinced, on the basis of what we have learned in California, that reducing sulfur emissions will, over the long term, lead to proportionate decreases in acid deposition in other parts of the Nation, too. I think a number of other scientists agree with this view.

But for sulfur dioxide, the proportionality may be somewhat less than 1 to 1, since it appears that sulfuric acid formation is limited, under some conditions, by the ability of the atmosphere to oxidize SO_2. This is basically what we found in Los Angeles.

Another point: If the oxidizing power in urban plumes here in the East is limited by the availability of nitrogen oxides, and a number of scientists think it is, then reductions in the emissions of nitrogen oxides would be expected to produce something more than a 1-to-1 decrease in acidity.

So a combined NO_x-SO_x strategy would appear to me to be an optimal one, especially when dry deposition is taken into account.

I am going to skip over the part on the meteorology and tall stacks and go on and conclude.

From my testimony, it seems clear enough to me that the climatological and other factors point to a multiplicity of sources to the south and west as being responsible for the high levels of acidity observed in precipitation in the Northeast and Canada. I think the time to act to reverse this trend is now, not later.

What actions can be taken now? Most important, I think Congress can hold the line on NO_x controls for cars. This is going to have a two-fold benefit, as I suggested. First, it is going to reduce the amount of nitric acid in precipitation. Second, it will reduce the capacity of the atmosphere to oxidize both sulfur dioxide and nitrogen oxides.

Proven technology to reduce NO_x emissions from cars to well below the 1 gram per mile standard we have now is readily available at relatively low cost. Relaxing the NO_x standard is going to provide little benefit for either the automobile industry or the consumer, as far as we can see, and the environmental benefits of retaining the standard are substantial.

Of course, there is also a very wide range of sulfur control options available. You have heard about them. I mentioned some of them to Senator Chafee. Controlling NO_x from stationary sources is a developing technology. Of course, demonstration units are operating in this country. In Japan, these units have been operating for several years on both coal-fired and oil-fired powerplants. They have a much more stringent NO_2 standard than we have here in the United States. So they have been controlling NO_x much more stringently.

Regulating in the absence of a full and complete scientific data base is, I think in this instance, fully justified. We have done this in California with photochemical smog. I discussed that in my testimony last October. This approach has worked. Strategies have been finetuned as a result of research over the years, but the basic approach that we adopted at the outset is still in effect and remains unchanged, and it is the same approach that is being used all across the country now. With acid rain in the Northeast, especially, the probable consequences of doing nothing for another 5 or 10 years I think are simply unacceptable. To delay action is, in my view, utterly irresponsible.

Thank you.

Senator **Stafford**. Thank you very much, Dr. Holmes. We appreciate your testimony.

The next witness will be Dr. Mohnen, director of the Atmospheric Science and Research Center in Albany, N.Y. Dr. Mohnen.

STATEMENT OF VOLKER A. MOHNEN

Dr. **Mohnen**. Before I start my official testimony, I would like to mention that Dr. Barrie has referred to something as the Mohnen hypothesis, which is a hypothesis, and Dr. Gould has cited my own work together with that of my coworkers, Dr. Kadlecek and Dr. Wilson. I would also like to mention the data Dr. Gould presented are from my research station at Whiteface Mountain. I will be happy to respond to you later but not as part of my official statement to the two previous testimonies.

The key challenge which atmospheric scientists face now is to establish a source-receptor relationship as a prerequisite to the development of a responsive control strategy to produce such a reduction in acidic deposition in sensitive areas. The source-receptor relationship must identify the magnitude of reduction in emissions of the substances contributing to or governing acidic deposition and the geographic regions in which such reductions must take place.

It is my opinion, based on my own research and based on my review of other past and ongoing research, that atmospheric scientists are not yet in a position to reliably establish this crucial source-receptor relationship for use in regulatory decisionmaking. What limited research has been done to date indicates that the reduction in sulfur dioxide emissions called for by the pending legislation would most likely not result in an equivalent reduction in acidic deposition in the sensitive areas and might—might—result in no measurable decrease in acid rain in those areas at all. This means that the control strategy adopted by these bills cannot be defended on the basis of science at this time.

Let me now try to explain the basis for these conclusions.

Wet deposition acid rain seems to be the dominant mechanism by which acidifying materials are delivered to sensitive areas in the Northeastern United States; in particular, to the Adirondack

Mountains. My research on wet deposition throughout the Eastern industrialized United States indicates that the amount of wet deposition is determined mostly by the amount of precipitation rather than by the amount and magnitude of upwind emission sources. If two-thirds of the rain on Whiteface Mountain comes from the Midwest, then two-thirds of the sulfate will come from the Midwest. If one-third of the rain comes from Canada, then one-third of the sulfate comes from Canada.

Our findings indicate that complex transport and transformation processes are at work in this region and that there is no simple linear relationship between emissions and deposition. In this region, the sulfur dioxide concentration in the atmosphere is not the limiting factor for the production of sulfate found in precipitation. Other substances, including NO_x, reactive hydrocarbons, ozone, carbon monoxide, and oxidizing agents such as hydrogen peroxide, hydroxyl radicals, and so forth, appear to control the sulfur transformation chemistry leading to wet sulfur deposition. This means that the reduction in sulfur dioxide emissions called for by the pending legislation will not result in an equivalent reduction in wet sulfur deposition in the Eastern United States.

Results from the European acid rain network support this conclusion. In that network, an increase—an increase—of 50 percent in sulfur emissions over a 10-year period did not result in any measurable net overall change in wet sulfur deposition in that region, and only in that region, not beyond.

Moreover, my conclusions are supported by a number of recent scientific panels and assessments, including the Jason Report on Acid Precipitation dated November 1981, the conclusions of a group of knowledgeable acid rain experts who testified in November of 1981 to the House Committee on Natural Resources, Agriculture Research and Environment, and a recent report of a Department of Energy-sponsored workshop on acid precipitation held in La Jolla, Calif., in January 1982. Just one conclusion of this last La Jolla workshop says, "The present state of knowledge of the source-receptor relationship in acid precipitation precludes significant policy guidance."

I have discussed and quoted extensively the conclusions of these panels and assessments in my written statement.

Turning now to the dry deposition of sulfur dioxide and sulfate particles, which also contributes to acidic deposition, the uncertainties are even greater, as we heard before. Science has not yet reached a stage where one can measure dry deposition with any degree of accuracy. Moreover, it is generally accepted that the importance of dry deposition decreases with distance from the emission sources due to the decrease in ambient concentration of SO_2, as mentioned by Dr. Barrie. I have observed the ambient concentration of sulfur dioxide at Whiteface Mountain in the middle of the sensitive Adirondack area and found in my network that SO_2 concentrations are extremely low. They are most of the time below 0.5 parts per billion—too low, as anyone knows, to contribute significantly to the dry deposition influx. It seems unlikely, therefore, that SO_2 reductions called for by the pending bill would result in an equivalent reduction in the dry deposition in the sensitive areas of the Northeast, particularly the Adirondacks. Even if some reduction in dry deposition in the sensitive areas did occur, its impact would be small because of the dominance of wet sulfur deposition in those sensitive areas that are located far away from emission sources. The closer you are to emission sources, the more dominant will dry deposition become.

In the field of air quality regulation, computer modeling is the most prevalent method of determining the source-receptor relationship for various pollutants, including SO_2. However, most current models assume a linear relationship between ambient levels of $S0_2$ and acidic depositions, as testified before, whereas the evidence now indicates that a linear relationship does indeed not exist, particularly in the Eastern, more-polluted United States. Current models also do not recognize the importance of copollutants in the SO_2 transformation process. Therefore, current modeling techniques cannot be used to determine the results of different SO_2 control strategies in terms of reducing either wet or dry acidic depositions in sensitive areas in the North American continent.

The limited research that has been done suggests that the required reduction in emissions would probably not result in the desired reduction of acid rain in those areas. Even after the emissions reductions mandated by the pending bills have been realized, we might very well still not have achieved the level of acidic deposition that some effects researchers have called for—meaning 50 percent.

Due to the complex interaction that exists among all substances suspended in the atmosphere, such reduction in SO_2 and NO_x could result in a measurable, if not significant, increase in the ozone concentration in certain regions. Therefore, we would have traded an impact on unmanaged land with an ozone impact on managed land.

A major remaining question is the time in which a reduction in acidic deposition must be achieved before irreparable damage in sensitive areas will occur. Based on my inquiries, effects researchers are generally unwilling to predict this time period. Although I am not an expert in effects research, I am led to believe that the rate of change in the observable effects of acidic deposition occurs over decades rather than years. An intensified acid rain research program, such as is being prepared by Chris Bernanbo at this time, is needed to resolve these issues and to monitor changes in the ecosystem.

As to the pending bills, the unfortunate fact is that they are attempting to regulate without any evidence or even likelihood that the control program established would have the desired effect—meaning a 50-percent reduction in deposition in certain sensitive parts of the country. Harold Macmillan once observed that politicians have to run hard to catch up with scientists. But in this instance it is my belief that the reverse is true; politicians better slow down and let scientists catch up with them.

Thank you very much.

Senator **Stafford**. Thank you, Dr. Mohnen.

Our next witness is Dr. Michael Oppenheimer, senior scientist, Environmental Defense Fund, New York, N.Y.

STATEMENT OF MICHEAL OPPENHEIMER

Dr. **Oppenheimer**. Thank you, Mr. Chairman.

Mr. Chairman, I am an atmospheric chemist. I have spent a good deal of time in the last couple of years studying the questions of transformation and transport of pollutants related to acid deposition. I have been running very hard to try to keep up with Dr. Mohnen because it was his work in part that stimulated the investigation and the basic research that I have undertaken.

I am going to address very quickly the questions that have been brought up today that I think are the most important ones; namely, what is the relationship between sulfur dioxide emissions and acidic sulfur deposition, and what is the scale of regional transport of sulfur in the Northeast? How far does the material that causes acid deposition travel?

In my remarks, I am going to restrict myself basically to comments on sulfur since it appears from a biological point of view to be the most important component of the acid deposition problem and is also responsible for three-quarters of the deposited acidic material.

I might say I disagree very strongly with Dr. Mohnen's statement on the current state of scientific understanding.

With your permission, Mr. Chairman, I would like to show a diagram.

Senator **Stafford**. Certainly.

Dr. **Oppenheimer**. This is a breakdown of the regional——

Senator **Randolph**. Can I make a suggestion, that we try to accommodate our guests and let them see it. We can also see it if you twist it just a little.

Dr. **Oppenheimer**. This is a diagram of the regional deposition of sulfur emissions. Sulfur is emitted in the Eastern part of the United States primarily by utilities. It becomes airborne sulfur dioxide, and once it is airborne sulfur dioxide, there are basically three pathways for its disposition in the atmosphere. Through so-called gas phase chemistry it could be turned into aerosol or airborne sulfates, then get involved in rain storms and be deposited as acid rain. These same aerosol or fine particle sulfates can be dry deposited as well. In addition, sulfur dioxide itself can be directly dry deposited. That is probably the primary path of dry deposition in the Northeast. Finally, sulfur dioxide can get involved with rain storms, as Mr. Hicks mentioned, and turn into acidic material in clouds and then again be deposited. All of these components together give you total acidic sulfur deposition which leads to the biological effects.

Now, on the question of linearity, for years there have been studies of the so-called gas phase pathway to acid deposition, particularly by Jack Calvert and other photochemists. I myself was originally a chemist and have looked at these pathways very carefully. There is absolutely not one scintilla of evidence that this pathway is anything but nearly linear. This pathway, the pathway for the production of acid deposition through rain storms, the so-called aqueous phase conversion, has been the subject of a lot of recent inquiry. I myself have done some work on it and published a peer reviewed article on the subject. I have been able to estimate the relationship of airborne sulfur or sulfur emissions to acid sulfur in precipitation which is produced according to this pathway.

My own research indicates, contrary to what Dr. Mohnen says, that this pathway is in itself very nearly linear as well, averaged over the Eastern States. I will put some numbers on that later.

Finally, as far as dry deposition is concerned, there have been some very limited discussions in the literature about the potential linearity or nonlinearity of dry deposition and, if one looks carefully at those studies, there is again no evidence whatsoever that regionally, in the Northeast, that this pathway is anything but very close to linear. There can always be very specific local situations, due to local meteorology, which would make each of these paths somewhat nonlinear. But the regional story is that all of these pathways are either precisely or very nearly linear. In fact, my own research indicates that if we were to reduce this quantity up here, airborne SO_2 emissions, and assuming, as most people now do, that the wet or aqueous pathway is the primary pathway for the production of acid rain, then a 50-percent emissions reduction would yield more than a 40-percent reduction in wet sulfuric acid. Given that the dry deposition pathway is probably regionally very nearly linear, it is my estimate that a 50-percent emissions reduction could yield very close to a 50-percent reduction in total acid sulfur deposition regionally.

Now, we have one more point. That relates to the scale of acid sulfur deposition. How far is the material transported? I know Dr. Rahn will have some comments on this. In my remarks, I am just going to deal with the material responsible for acid deposition.

Now, we know how much acid rain is deposited. There have been networks going for several years now. This box can be counted. We know how frequently it rains. That is, this box is understood in the statistical sense. Therefore, we can understand what is the likelihood that material which is emitted gets deposited as acid rain. Given that it only rains approximately one out of every five days in the Northeast, in order to get as much sulfur in rainfall as we actually see in the networks, the sulfur has to stay airborne for quite a few days. If it did not stay airborne for quite a few days, we would never see as much sulfur in rain as we actually measure. Therefore, during that several days of airborne existence for the sulfur, it has been moved around the Northeast by the prevailing winds, several hundred miles a day, in general, on average. The net effect is that the emissions which are precursors to acid rain, the sulfur part of it, are transported on average many hundreds of miles, probably 500 to 1,000 miles, meaning that we have a regional scale problem with emissions from the Midwest being a very important component of the problem, as has been stated by others here today.

So I want to state in conclusion that I believe that the state of atmospheric chemistry, while somewhat uncertain as far as specific sources and specific receptors is concerned, is well understood from a regional point of view, and that a significant reduction in sulfur emissions will lead to a significant reduction in total acid sulfur deposition, and even in wet deposition, in and of itself, and that each and every part of the Eastern United States contributes a significant share to the sulfur deposition in the sensitive areas of the Northeast.

Thank you.

Senator **Stafford**. Thank you very much, Dr. Oppenheimer.

The next witness will be Dr. Kenneth Rahn, associate research professor, Graduate School of Oceanography, University of Rhode Island, Narragansett, R.I. Dr. Rahn.

STATEMENT OF KENNETH A. RAHN

Dr. **Rahn**. Thank you very much, Mr. Chairman. I am an atmospheric chemist and I would like to state at the outset that I have come in the back door in the field of acid precipitation very recently, in the past few months.

I would like to now, in the next few minutes, give a synopsis of the prepared statement that has been submitted and very briefly recite what has happened to me since approximately last September and why it has thrown such confusion into my own mind at least on a number of aspects concerning the acid precipitation question.

One of the most crucial aspects of acid precipitation in the Northeastern United States, and many pollutants in general, is the degree of regionality. To effectively control any pollutant, one first has to determine the regionality of its sources and transport. After establishing the boundaries of the region to be controlled, one can begin to control, normally with the largest source first.

During the past decade or so, there has been a generally increasing awareness of the regional scale of many air pollution phenomena. A decade ago we and many people imagined these were relatively local problems, and now it is realized in many cases that this influence of large pollution sources extends to hundreds, perhaps thousands of miles in some cases. These are indeed laudable. Long-range transport of pollution is rare. My own personal feeling is this is even more common and widespread than recognized in many quarters today.

Evidence in support of the long-range explanation of acid precipitation in the Northeastern United States is massive and convincing. The distances of transport from the Midwest, roughly 600 miles, are the same as those documented in many studies from central Europe to southern Scandinavia and are trivial compared to other examples of long-range transport elsewhere in the world.

One of these I have personally worked with is the Europe and Asia to the Arctic, where distances of transport were on the order of 3,000 to 6,000 miles. That is 5 to 10 times longer than anything we are talking about here in the United States.

But is the long-range explanation really the correct one for the Northeast or is it the only possible one? During the past 8 months or so I have accidentally uncovered counterevidence which suggests that while there is certainly routine long-range transport into much of the Northeast, its importance relative to local—that is Northeastern—sources may often be considerably less than previously imagined. Today I will review some of this new evidence and its implications for the control of acid precipitation.

At the outset, I would like to put several qualifications on what I am about to say, which I might say are not always put on by people who are referring to this work. [Laughter.] This evidence is largely preliminary and incomplete. It is not the result of any formal, funded study. It is a spinoff from our project in Arctic air chemistry. It deals with aerosol, not precipitation. It deals with trace elements in the aerosol, not with its acidic component. And it is now recognized, as has been mentioned by Dr. Barrie and others today, that acidic aerosol is not necessarily the major source of acid precipitation.

What happened to us in our studies of the Arctic was this. We were faced with a very difficult problem of determining source areas of pollution aerosl many thousands of miles from their sources. We tried for several years, the normal meteorological period, to produce such a trajectory, and they failed in the Arctic.

We were lucky enough, and this was in conjunction with a telephone conversation with Dr. Barrie that this whole thing got started about 2 years ago, to determine new ways of tracing sources of pollution even after long-range transport. We are working with aerosol tracers or signatures or fingerprints, call it what you will, on different sources on a regional scale, such as, for example, the Northeastern United States, Western Europe, that sort of thing.

Although these signatures undoubtedly involve many elements, we have to date used only two, manganese and vanadium in the form of a ratio. The manganese and vanadium ratio, or more properly the ratio of noncrustal manganese to noncrustal vanadium, is about 10 times greater in the Midwest than it is in coastal regions of the Northeast, between roughly Boston and Washington. By measuring the manganese-vanadium ratio in Northeastern aerosol, one can therefore in principle determine whether it, the aerosol, has originated in the Northeast, in the Midwest, or in some combination of the two regions.

We sought to use this approach to confirm—and I stress confirm because I wasn't a complete believer in the long-range transport—the Midwestern origin of Northeastern aerosol, particularly during episodes of high sulfate, which occur commonly during summer and have been used by others as the basis for judgments on the importance of long-range transport in the Northeast. If the sulfate, acidity, and associated pollution aerosol really came from the Midwest, the aerosol of these episodes should carry with it high—Midwestern—manganese-vanadium ratios. By contrast, aerosol between episodes should have much lower—that is Northeastern—manganese-vanadium ratios.

We have at present data sets from four locations in the Northeast whose manganese-vanadium ratios have been measured. What they tell us provides a rather new, interesting, and different picture, I believe, of where air pollution in the Northeast really originates.

The largest, most comprehensive set of data we have so far comes from just outside our laboratory in Narragansett, R.I. It totals at present over 200 aerosol samples taken during nearly 3 years. These samples show very clearly based on their elemental signatures that practically all the aerosol, at least manganese and vanadium components and other elements they represent, has an

Eastern or Northeastern origin rather than a Midwestern origin. On odd occasions we can see Midwestern transport. We can see transport from the Southeast occasionally. We believe we can pick up aerosols from Canada from time to time. But the great majority of cases we are seeing home-grown, if you will, Northeastern aerosols in my opinion.

Needless to say, we were greatly surprised by these results. They were communicated preliminarily in the statement of the 23d of November of last year, which has become the subject of great discussion and debate. Since then we have generated more data from other sites. We have one from Glen, N.Y., which is 40 miles west of Albany, which showed similar results. This shows it from this winter. By the time you get approximately 200 miles inland, the aerosol shows a widely diverging character based on the previous history of the airmass. If the airmass is one that obviously came from the Midwest, it has the Midwestern stamp on the ratio. On the other hand, more than half of the time the aerosol shows a very strong Eastern stamp.

We interpret these results from these sites to mean there is no such thing as the Northeast. Rather, the Northeast is comprised of at least two atmospheric systems with different sources of aerosol. The coastal Northeast, represented by Rhode Island, experiences northeastern, or local, aerosol most of the time. Beginning approximately 200 miles or so inland, a transition zone is encountered which can experience either northeastern or midwestern aerosol, depending on the history of the particular air mass. Farther westward, an area is reached which receives midwestern aerosol most of the time. We expect, but cannot yet prove, that western New York State, probably including the Adirondacks, is in this region. The aerosol of northeastern New England—Vermont, New Hampshire, Maine—is still unstudied. In short, aerosol composition in the Northeast varies systematically from east to west, with increasing effects of midwestern sources seen toward the west.

There have been a number of potential problems raised concerning this new technique of elemental tracers. I perhaps can go into these in the question and answer session. It is my opinion that the criticisms are all answerable, and the general sense of the results has held up during the past several months.

Implications of these results relative to these hearings are:

One, a 31-State regulatory region for acid precipitation may be too large. According to our data, the prevalent distance scale, at least for pollution aerosol, is roughly 200 miles. That is to say the effects downwind of strong source regions decrease rapidly beyond roughly the 200-mile region. This varies depending on the area. In some cases it may be less than 200 miles. In some cases you may very well see effects beyond 200 miles.

Two, the Eastern United States may be composed of two or more source-receptor regions, not just one. If so, appropriate emission standards for each region may differ, as dictated by the ecological characteristics of the individual receptor areas downwind.

Three, consequently, a single emission standard for sulfur dioxide, as proposed in the bills currently before the Senate and House, may not be justified atmospherically.

Four, strong controls placed on midwestern sources of SO_2 may not affect acid deposition in regions of the Northeast which are not directly in the midwestern receptor area, such as coastal New England. To reduce acidity in these regions, northeastern emissions, which are already low, may have to be reduced still further.

In conclusion, then, our new data have suggested that the system of sources and transport of pollution aerosol in the Northeast is considerably more complex than was recognized previously and that substantial portions of the Northeast may be influenced primarily by northeastern rather than midwestern aerosol, even during sulfate episodes. If this view is correct, it casts considerable doubt on the popular view of the Midwest as the dominant source of acidity throughout the Northeast.

From recent contacts with scientists working in other aspects of acid precipitation, I have learned that similarly large uncertainties exist in many of their areas, the depths of which are not generally appreciated by nonspecialists. It is my impression that many of these problems can be resolved with a few years of intensive effort, such as we have heard already today. Considering the decades or centuries that acid precipitation has been with us, a few years' wait is not critical in my judgment. Now that the Congress has passed the Acid Precipitation Act of 1980 and has called for a decade of concentrated research, I see no scientific reason why we should assume the answers before the research has hardly gotten underway. To legislate strong controls on certain pollutants before the entire system is understood, especially when those controls are focused on one area of the country, seems to me to be several years premature at best and potentially disastrous economically at worst. The left hand has just given us 10 years, but the right hand wants to act now. There is no ecological crisis that demands such rapid action, in my opinion. Now that you have at last given us the means to work on this problem, please give us the time.

Senator **STAFFORD**. Thank you, Dr. Rahn.

The final member of the panel is Dr. Jack Shannon, Argonne National Laboratory, Argonne, Ill.

STATEMENT OF JACK SHANNON

Dr. **SHANNON**. Thank you, Mr. Chairman. I am a meteorologist by training.

My research is in the area of computer simulation—that is, modeling—of the combined processes of long-range transport, chemical transformation, and wet and dry deposition of pollutants contributing to acid deposition.

There are a number of uses of modeling, including the interpolation of data between stations where you take measurements, the diagnostic analysis of data gathered in field experiments, and the objective estimation of the changes in concentrations or deposition resulting from an emission change. The last application, obviously, is the one that arouses the most comment. So I would like to explain briefly what is involved in modeling.

Computer simulations are mathematical descriptions of the complex processes involved from emissions through plume rise, mixing by turbulent diffusion, transport by the winds, transformation en route by chemical processes, scavenging by precipitation, and dry deposition by processes of diffusion and impaction at the receiving surface.

While none of these mechanisms are completely understood, some processes—such as emission rates, plume rise and short-range dispersion—have been investigated for a number of years for other air pollution problems and are reasonably well understood. Similarly, the meteorological processes of long-range transport have had to be studied for a number of years for purposes of weather forecasting because you have to understand the movement of air masses. So we have a good bit of knowledge there. That is one reason why the results of models which are quite a bit different in their structure often are quite similar, because we did understand the transport at least reasonably well. The other mechanisms are a good bit more complicated to investigate.

Chemical processes are most easily studied if you are in a laboratory. The real atmosphere does not have edges. It is hard to measure everywhere in a hypothetical box. It is just difficult to control conditions in the field.

We can both measure and monitor precipitation chemistry, but the short-range variations in time and space of both the precipitation process itself and the air quality make analysis of a single event extremely difficult.

The rate of dry deposition depends both on the pollutant and on the surface to which it is deposited. In other words, you get different dry deposition on a coniferous forest and an adjacent field of corn.

This process cannot yet be successfully monitored, but it can be measured for some pollutants in exacting field experiments. We have people on the panel, Mr. Hicks and Dr. Barrie, who have both been engaged in such experiments.

Modeling thus involves the synthesis of a number of complex processes. But not all of what is produced by modeling can be compared with monitoring observations because of this problem of dry deposition not being monitored.

Modeling of acid deposition to date has generally been limited to modeling of the deposition of sulfur pollutants. Since the sulfur pollutants seem to account for about two-thirds of the deposition related to acid processes in the Northeast, it seems to be a good surrogate for acid deposition in that area. It is obviously not going to be a good surrogate in California.

The use in the Northeast is supported by a general similarity between the simulation of total sulfur deposition patterns and the observed patterns of hydrogen ion deposition, the fundamental measure of acidity. We modelers are aware that we need to be including nitrogen oxides in our calculations, and we have made some attempts there. But the state of the science of modelinq the nitrogen oxide system is behind the science of modeling the sulfur oxide system. We are able to model deposition more accurately as our time scale of interest increases. In other words, if we model a deposition for a season or for a year, we can treat that better than if we are trying to model a deposition for a single rain shower. Similarly, we can model deposition over an area, a State, a number of States, more accurately than we can model a deposition at a point. This is because many of the necessary input data are estimated only as averages over a large time and space scale. Emission rates are known mainly as annual values, although we know there can be large emission variations in particular sources.

Modeling is thus best able to address the question of what the emissions from a State or several-State region will do to the deposition in a State or several-State region better than it is able to address the question of what the emissions in a plant in Pittsburgh, Pa., today will do to deposition in Portland, Maine, tomorrow.

Modeling results are inherently more accurate in a relative sense than in an absolute sense. This is due to the fact if you are addressing different scenarios, for instance, looking at current emissions and looking at the emissions that the legislation that has been introduced would imply, the modeling errors will be common to both scenarios and tend to produce similar underprediction or overprediction, but will have less effect on the relative change.

Since long-range transport and deposition modeling is not an end in and of itself, the form of the modeling output should be that which will be most useful to the next user along the line; that is, the people who have to investigate the ecological effects, materials damage, and health effects.

There is a viewpoint now in the ecological community which I think will probably be expressed in the other session if the preliminary list of people on the panel is accurate, that it is not the pH of the rainfall that is important; it is the total deposition of the sulfates and nitrates. If so, then the output that we as modelers should produce should be the total deposition of sulfates and nitrates. If, on the other hand, the critical matter is the occasional ecological insult, the low pH storm, then that is the output we should strive to indicate.

Confidence in our ability to model or simulate potential future acid deposition patterns, or our ability to analyze changes in depositions associated with emission changes, will be increased if we can reproduce historical trends. Analyses of computer-simulated sulfur deposition patterns in eastern North America at roughly 10-year intervals since 1940 indicate that the greatest change has been an extension of areas of relatively high deposition toward the South and Midwest. There does not seem to have been a dramatic increase in maximum deposition in the Northeast. This result is supported at least in the wet deposition component by the available historical patterns of precipitation acidity in these regions. There are considerable uncertainties in both modeling and data analysis, since the information on past emissions and on powerplant stack heights, which is a critical factor here, is not all that could be desired and because in the past, precipitation pH measurements had different quality control and analysis procedures. But the general agreement is very encouraging.

Moreover, with the standardization of acid precipitation monitoring procedures now being adopted in both this country and Canada, we modelers can look forward to increasingly dependable information on spatial distributions and historical trends. It remains for modelers to include adequate simulations of the contributions of the nitrogen oxides. It remains for the monitoring networks to find ways to include the contributions of the dry components.

I would like to make another comment. It is not a part of this written statement. It is related to what Dr. Rahn said about the large share of local source contribution to the sulfate concentrations in the Northeast.

In the use of a model which produces results which are broadly those described by Dr. Barrie at the start, I found that the primary sulfate contribution—that is, the sulfate emitted in that form, from the stack rather than made by transformation in the air—the primary sulfate was dominant over the secondary sulfate, that is produced by atmospheric transformations, in the northeastern urban area during the winter, particularly, in the area roughly Washington-Boston. And so I find that the results of that particular long-range transport model are in general agreement with Dr. Rahn's results, and I find that encouraging.

Thank you.

Senator **STAFFORD**. Thank you very much, Dr. Shannon.

Having completed the panel, I will begin to express our appreciation on behalf of the committee.

Before we go to questions, the Chair would propose that we limit ourselves to 10 minutes in the first round, and there will be a second round as long as members of the committee wish to ask questions.

Before we get to questions, this would be a good time for Members to place opening statements in the record. Senator Randolph, did you wish to place a statement in the record?

Senator **RANDOLPH**. Thank you, Mr. Chairman.

Mr. Chairman, Senators Ford of Kentucky and Byrd of West Virginia would like to place statements in the record along with the other members of the committee.

Senator **STAFFORD**. Without objection, we will do so.

[The statements follow:]

STATEMENT OF HON. ROBERT C. BYRD, U.S. SENATOR FROM THE STATE OF WEST VIRGINIA

Mr. Chairman, thank you for the opportunity to address the committee on the phenomenon of acid precipitation. For the information of the committee, I wrote to Chairman Stafford on May 5, 1982, to respectfully request that the Committee on Environment and Public Works consider holding hearings on acid precipitation. I also made by request know to Senator Randolph, as ranking minority member of the committee.

My letter suggested that there are large uncertainties associated with scientific theories that purport to describe the phenomenon of acid precipitation. As a United States Senator, and not a scientist, I cannot comment directly on the relative value of one theory over another. The fact that I am not a scientist, as is the case with most Senators, requires me to scrutinize carefully any legislative proposal that purports to be based on sound, scientific evidence—and that would result in economic disruption in my state of West Virginia.

For that reason, my letter to the Chairman suggested that scientific testimony would aid Senators in gaining perspective—to discover how much diversity there is within the scientific community on this subject.

It should be clearly understood that a proposal to control acid precipitation would be a difficult pill for my State to swallow—as it would be for many other States in the Appalachian and Midwest regions of America. And the statement made in the preceding sentence assumes that such a proposal would be advanced on the strength of indisputable scientific agreement as to the causes and effects of acid precipitation. It also assumes that indisputable scientific agreement would exist as to which control measures would be effective in reducing or alleviating acid precipitation.

Such agreement does not exist. If there is any message that the scientific community has transmitted loud and clear on this matter, it is that they do not really understand what this phenomenon is all about. They cannot agree on what it really is, or where it actually comes from.

If we as Senators hear this message from the scientific community, how can we responsibily attempt to make a regulatory policy that assumes that we know the answers that the scientists do not know?

This is a critical consideration, as the logical basis for acid precipitation proposals rests on one's acceptance of the premises that we do know what we are dealing with and how best to control it. The scientific community has not assured me in the least that this is the case.

It is as if Senators were being asked to blindfold themselves and fire weapons at a distant target. We would be likely to do more damage to ourselves than the target.

I ask my colleagues and friends on the Committee on Environment and Public Works to consider with the utmost care the basis on which the various acid precipitation control proposals are founded. Proposals that are arbitrary, or that make fundamental assumptions as to the source of responsibility for acid precipitation will not serve our country's best interests.

As the members of the committee know, I have introduced legislation that would seek to increase our present knowledge. I raise this to indicate that there are ways to address the phenomenon of acid precipitation without prejudging the scientific case on it.

I ask that a copy of my letter of May 5, 1982 to the Chairman of the Committee on Environment and Public Works, and material from a variety of scientific, technical, and academic sources be included in the record of this proceeding at an appropriate point.

STATEMENT OF HON. WENDELL H. FORD, U.S. SENATOR FROM THE STATE OF KENTUCKY

I am pleased that, as the Committee on Environment and Public Works considers amendments to the Clean Air Act, it is taking the time to review the acid rain phenomenon. Legislation currently pending before the Committee, S. 1706 and S. 1709, and the amendment you yourself have proposed seek solutions that, in my view, are premature. I hope that evidence presented during this series of two hearings will reinforce this fact and will prompt the Committee to consider a different approach to the problem of acid deposition.

The three proposals advocate the reduction of sulfur dioxide emissions from coal-burning utilities of 60 percent or more in a 31-state area which encompasses all of the states east of and some immediately adjacent to the Mississippi River. Their formulas have been carefully crafted so that their impact would be the least on those northeastern states where the effects of acid rain are allegedly the most serious and the heaviest on the states of the Midwest. The economic impact of this control strategy promises to be devastating. In my state of Kentucky alone it is estimated that over $700 million would be added annually to utility bills in a time of severe inflation and unemployment. This figure does not include a one-time cost of some $1.5 billion in control costs.

The unequal distribution of the economic burden that acid rain legislation would impose on the non-New England states needs to be addressed. First, eight midwestern states would be required to reduce sulfur dioxide emissions by five times the amount of northeastern states. Second, although estimates vary, the total cost to eastern electric utilities of implementing these bills ranges from $3 billion to $7 billion annually. Third, coal production dislocation could total as much as 300 million tons per year. New England produces no coal and thus would not be affected, but losses of coal production in the Midwest to other areas of the country could range between 63 and 109 million tons a year. Finally, since to achieve emissions reduction low-sulfur coal would be substituted for high-sulfur, coal mine job displacement could rise to 75,000 or as high as 89,300. Total jobs affected, including indirect employment, could be as high as 300,000. Much of this hardship would occur in Appalachian and midwestern states, those states that now suffer from the country's highest unemployment rates. Total personal-earning losses would equal about $7 billion annually (in 1982 dollars). This includes $2.5 billion in miner earnings and $4.6 billion for non-miners.

The worst part of this grim scenario is that the acid rain program envisioned by this legislation is being proposed in the face of scientific uncertainty about the causes of acid rain. The case has just not been made that the proposed strategy for controlling sulfur dioxide emissions will result in any measurable reduction of acid rain in the Northeastern United States for the following reasons:

1. Specific source-receptor relationships cannot be established. Scientists say that it is not feasible to identify the contribution of individual sources to an area affected by acid rain.

2. There is no linear relationship between midwestern emissions and acid rain in the Northeast. Wet acidic deposition at sites in the Northeast and Midwest was found not to depend on the emission levels in the regions over which the air had passed, but mainly on precipitation amount.

3. The limiting factor in the formation of acid rain appears to be the availability of oxidizing agents, not the sulfur dioxide concentration.

4. Local and other non-midwestern sources appear to be a greater cause of acid rain in the Northeast than was previously believed. High sulfate levels at two sites in the Northeast were found to be associated primarily with eastern source areas, not with the Midwest. Something none of the sponsors of the proposed legislation have been willing to discuss is the possibility that local oil burning and gasoline consumption may be a significant cause of acid rain in the Northeast.

5. The Environmental Protection Agency and the Comptroller General have recognized the major uncertainties about the causes of acid rain and thus about the cures for it.

I certainly cannot blame my colleagues from the Northeast for wanting to cure the acid rain problem. But I strongly believe that anyone who looks at the data available from the scientific community can only conclude that the facts are not all in. Senator Randolph has submitted for the hearing record a half dozen studies that disagree with the basic premise of S. 1706, S. 1709 and the Stafford amendment that a regional reduction in sulfur dioxide emissions will control acid rain in the Northeast. There is certainly enough disagreement about the causes of acid deposition—particularly about the nature of long distance transport, to warrant further study. To impose massive regulatory requirements on utility sources before conclusive information is at hand would be politically irresponsible and economically damaging.

I respectfully suggest that the Committee seriously consider legislation such as that proposed by Senator Robert Byrd in S. 2027 and again in Title IV of S. 2266. Senator Byrd's intention is to accelerate the national acid precipitation assessment plan established under Title VII of the Energy Security Act so that it will be concluded in five years instead of the currently mandated ten. As you know, the House Committee on Energy and Commerce has adopted by a wide margin language accelerating the study so that, as in the Byrd language, all results will be available after five years.

I would appreciate your including in the printed hearing record both this statement and its accompanying attachments, which are a letter from the Kentucky Department of Energy discussing Kentucky's concerns with a regional approach to acid rain control and two fact sheets from Peabody Coal Company describing the economic costs of and the scientific case against this legislation.

With thanks for your kind cooperation.

JOHN Y. BROWN, JR.
GOVERNOR

WILLIAM B. STURGILL
SECRETARY

DEPARTMENT OF ENERGY

December 23, 1981

Senator Robert T. Stafford
5219 Dirksen Senate Office Building
Washington, D.C. 20510

Dear Senator Stafford:

I would like to express our concern with the proposed acid deposition bills, S.1706 and S.1709, which have been introduced to the Senate Environment and Public Works Committee.

Our concerns are that implementation of neither bill would solve the acid deposition problem, but either would cause severe economic hardship on select geographic areas.

The testimony of Robert M. Friedman, Office of Technology Assessment, presented before your committee on October 29, 1981, reveals the following:

1) New York state emits roughly as much sulfur dioxide as Kentucky

2) The Mitchell bill seeks a 63% reduction of Kentucky emissions, but only a 21% reduction of New York emissions. Following enactment of the Mitchell bill, New York would emit over twice as much sulfur dioxide as Kentucky

3) The Moynihan bill seeks a 71% reduction of Kentucky emissions, but only a 7% reduction of New York emissions. Upon enactment of the Moynihan bill, New York would emit over three times as much sulfur dioxide as Kentucky.

While it may be apparent why Senator Moynihan chose to introduce his own legislation rather than co-sponsor Senator Mitchell's, it is quite apparent that enactment of either piece of legislation would be highly inequitable to Kentucky and, more importantly it is not likely to reduce acid deposition in the Northeast U.S. (e.g., the Adirondacks). The inequitable allocation of reductions is largely due to the focus of the bills on emissions from electric utilities, thus penalizing states whose emissions are produced predominantly by electric utilities. Sulfur dioxide produced by electric utilities is no more likely to cause acid rain than sulfur dioxide produced by industrial sources or any other source. In fact, studies by EPA and others indicate the contrary.[1]

KENTUCKY CENTER FOR ENERGY RESEARCH
P.O. Box 11888

When sulfur-bearing fuels are burned, a variety of sulfur oxides are produced, including sulfur dioxide and various sulfites and sulfates. It is the sulfates that directly contribute to acidity. Sulfur dioxide and the sulfites must be chemically converted to sulfates to affect acidity. The studies referred to above indicate several important conclusions:

1) Combustion of sulfur-bearing fuels in utility boilers, due to sophisticated technologic design and controls, produce a lower percentage of sulfates than combustion in industrial, commercial, and residential boilers. Hence, states which produce sulfur oxides primarily from utility boilers are likely to be producing less of the acid sulfate than states which produce an equal amount of sulfur oxides from nonutility boilers.[2]

2) Combustion of oil, especially residual oil, produces a higher percentage of acid sulfates than combustion of coal with a similar sulfur content. This is believed to be caused by the catalytic properties of trace elements found in oil, such as nickel and vanadium (which is used as a catalyst in sulfuric acid manufacturing plants)

3) The trace metals from oil combusition that are released into the atmosphere continue to act as catalysts in the conversion of sulfur dioxide to sulfates.

Hence, it is likely that sulfur oxides produced by oil burning, especially in industrial and other nonutility boilers, are indeed more likely to contribute to acid formation than equal amounts of sulfur oxides produced by coal-fired utilities. Thus, New York, with over half of its SO2 emissions emanating from oil combustion, could be contributing a significantly higher amount of acid sulfates than Kentucky, which emits the majority of its SO2 from coal combustion in electric utilities.

Conversion of sulfur dioxide to acid sulfates in the atmosphere usually takes place at a low rate. The conversion is accelerated by the trace metal catalysts, mentioned earlier, and by photochemical oxidants, including ozone and hydrocarbons. Some of the highest concentrations of these oxidants in the U.S. are found in the major cities of the Northeastern U.S. The entire state of New Jersey, for example, has been classified as nonattainment for photochemical oxidants.

Furthermore, as should be obvious to anyone, these important sources of acid sulfates in the metropolitan Northeastern corridor are within only several hundred miles of the sensitive regions of New England

and eastern Canada, while the major Kentucky utilities are over one thousand miles away. In spite of strong evidence indicating that local sources are the primary causes of acid rain, the proposed legislation ignores the evidence and mandates the greatest expenditures from remote sources which produce less of the acid-forming compounds. With no evidence that long-range sources are the major cause of the problem, the proposed legislation amounts to a requirement that Kentucky and neighboring states pay a disproportionate share for the problems that may be largely created and experienced in our Northeastern states.

Much of the misunderstandings concerning the acid rain issue arise from overly-simplified explanations. The "tall stack" theory of lofting pollutants high into the atmosphere to be carried thousands of miles is largely unfounded. After a distance of only about 50 miles, levels of contaminants are virtually independent of stack heights. Atmospheric models attempting to predict long-range transport do not even consider stack heights. The "prevailing Westerlies" and the maps we see showing prevailing winds from the Midwest to New England are also misleading. Winds very frequently travel in all other directions; they clearly do not travel continuously along this route.

Acid deposition has been documented to have the most severe impact during the spring thaw when acid compounds deposited in snow and ice are released. Ontario has stated that up to 76% of the acid discharges from monitored watersheds runs off in April.[3] During the winter months when these compounds are deposited in ice and snow, the prevailing winds are more from the North not the Midwest. Ontario has also measured rainfall with a pH of 4.6 associated with winds arriving from North of Ontario.[3] This is not to say that the acid comes from the North Pole but rather that it is likely to come from locally producing sources.

Considering the emissions from the Ohio River Valley, it should be noted that the ORBES study found that utility sulfur dioxide emissions will be reduced significantly as all facilities are forced to comply with existing State Implementation Plans and as existing plants are retired and replaced by new plants meeting New Source Performance Standards. The study concluded that under the base case estimate electric generating capacity in the Ohio Valley region (includes parts of six states: Illinois, Indiana, Ohio, Pennsylvania, West Virginia, and Kentucky) would increase from 83 GW in 1976 to 153 GW in the year 2000; but in spite of this nearly 2-fold increase in generating capacity, SO2 emissions were projected to decrease by over 50%! Thus, it appears that substantial emission reductions will occur in this region without the need for further legislation or regulation.

If it is believed necessary to take action before the facts are known, any legislation should consider the above and other studies to result in more equitable allocations than those proposed. We believe, however, that the most beneficial expenditures would be toward increased and accelerated research so that the problem may be addressed and remedied in a rational manner.

Sincerely,

William B. Sturgill
Secretary

REFERENCES

1. J. B. Homolya and J. L. Cheney, "Workshop Proceedings on Primary Sulfate Emissions from the Combustion of Fossil Fuels" Vol. 2 EPA-600/9-78-0206, U.S. E.P.A., RTP, N.C. 1978 pp 3-13

2. J. B. Homolya and S. Lambert, "Characterization of Sulfate Emissions from Nonutility Boilers Firing Low-S Residual Oils in New York City." Journal of the Air Pollution Control Association. February 1981 Volume 31, No. 2

3. Ontario Ministry of the Environment, "A Submission to the United States Environmental Protection Agency Opposing Relaxing SO2 Emission Limits in State Implementation Plans and Urging Enforcement" March 12, 1981

fact sheet

PEABODY COAL COMPANY

ECONOMIC COSTS
OF PROPOSED ACID RAIN LEGISLATION

HIGHLIGHTS

Economic analyses of the costs of implementing S. 1706 or H.R. 4829 indicate that there would be a great and unequally distributed burden placed upon non-New England states, despite the unlikelihood that any measurable benefits would accrue to the New England and New York states the bills were designed to protect.

1. Total Emission Reduction Requirements. The bills call for average SO_2 emission reductions of 45% by 1990 in a 31-state area east of and immediately adjacent to the Mississippi River. Eight (8) midwestern states would be required to reduce current emissions by an average of 58%, while New England states would be required to reduce emissions by an average of only 12%. (source: Office of Technology Assessment)

2. Coal Production Displacement and Losses. Coal production dislocations from one state to another could total as much as 300,000,000 tons yearly. New England states do not produce coal and therefore would not be affected. Complete losses of coal production in the Midwest to other areas of the country could range between 63 and 109 million tons annually. There would also be slight production losses in the East. (sources: ICF Incorporated and Peabody Coal Company)

3. Economic Displacement and Losses. Under one set of assumptions which called for achieving the emission reductions by substituting low-sulfur coal for high-sulfur coal, coal mine job displacement could rise to 75,000 or as high as 89,300. Total jobs affected, including indirect employment, could be as high as 300,000. Much of this hardship would occur in those Appalachian and midwestern states that presently have the highest unemployment rates in the country. Total personal earning losses would equal about $7.0 billion annually (1982 dollars). This includes $2.5 billion in miner earnings and $4.6 billion for non-miners. (sources: United Mine Workers of America and Peabody Coal Company)

4. Total Electric Utility Costs. Under another set of assumptions, the total cost to eastern electric utilities of implementing the bills would be at least $6.9 billion annually, according to one source. However, 1 utility system claims that the cost of implementing the bills to its customers alone would total about $2 billion annually. This would raise the system's rates to its 2.25 million customers by an average of 63%. (sources: ICF Incorporated and American Electric Power Service Corporation)

Costs of Implementing S. 1706 in 1990*

	OTA	EEI/ICF	Peabody	UMWA
Total Annual Electric Utility Cost Increases**	$3.3-$4.1 billion	$6.9 billion	$4.0 billion	-
Total Electric Utility Capital Cost Increases	-	$26.2 billion	-	-
% Increase in Annual Emission Reduction Costs	57%-71%	-	57%	-
Coal Production Displacement	-	-	243,000,000 tons	243,000,000 tons
Production Losses in East and Midwest	-	63 MM tpy	109 MM tpy	-
Coal Miner Unemployment	-	-	75,000	89,300
Total Unemployment	-	-	300,000	-
Personal Income Losses	-	-	-	$7.0 billion
Assumptions				
Total Emission Reductions	10.0 MM tons	13.1 MM tons***	10.0 MM tons	10.0 MM tons
Interstate Emissions Trading	no-yes	no	no	no
Method of Complying	least cost	least cost	coal switching	coal switching

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* all figures in January 1982 dollars

** the American Electric Power System estimates that annual costs to its customers alone would equal about $2.1 billion

*** interprets S. 1706 to mean no emissions growth permitted

ECONOMIC ANALYSES OF PROPOSED ACID RAIN LEGISLATION:

Introduction

Legislation proposed in Congress (S. 1706 and H.R. 4829) seeks to alleviate the incidence of acid deposition in the Northeast by requiring reductions approaching 50% of current emissions of SO_2 over 31 eastern states. Scientific evidence presented in numerous studies indicates that the emission control strategy adopted in these and similar bills probably would not result in significant reductions in acid deposition in sensitive areas. Scientific findings are summarized by Peabody in another document. The costs of complying with the legislation have been estimated in a number of studies by interest groups, industry, and government and are summarized on these pages.

Summary of Economic Studies

S. 1706 and H.R. 4829 would require each state to reduce emissions of SO_2 by a share equal to its emissions in excess of 1.2 lbs. per million BTUs as a proportion of all such emissions in the 31-state Acid Rain Mitigation Study (ARMS) Region. This requirement would result in an inequitable burden of costs to states other than those perceived to have acid deposition problems. This inequity extends to the total emissions that must be reduced; coal production displacement and losses; associated employment displacement and losses; associated income displacement and losses; and the total cost of fulfilling the requirements imposed by the legislation. In each of these categories, the non-New England states bear a higher burden of the costs than the New England states, with 8 states assuming well over half the total. Studies by ICF Incorporated for the Edison Electric Institute, the Office of Technology Assessment (OTA), Peabody Coal Company, the United Mine Workers of America (UMWA), and individual electric utilities are summarized.

Total SO_2 Emissions That Must Be Reduced

According to OTA, S. 1706 would require the 31 states in the ARMS Region to reduce SO_2 emissions by 45% below current levels[1]. The average quantity of emissions to be reduced for the 8 highest states is 915.6 thousand tons per year versus a 26.6 thousand average for New England states. The average percent reduction in total emissions required for the 8 highest states is 58% compared to 12% for the New England states. The individual figures for the 8 highest and the 6 New England states are as follows:

State	Absolute Reduction (10^3 Tons)	Percent Reduction From 1980 Levels
Ohio	1,617.5	57.8
Indiana	1,191.3	57.3
Missouri	911.1	67.6
Pennsylvania	876.7	40.5
Illinois	770.2	50.2
Kentucky	696.8	62.9
Tennessee	679.0	62.5
West Virginia	582.4	53.2
Massachusetts	106.4	22.2
New Hampshire	50.1	46.1
Maine	2.7	2.8
Vermont	0.1	0.7
Connecticut	0.0	0.3
Rhode Island	0.0	0.0
All 31 States	10,000.0	44.8

Coal Production Displacement and Losses

Two studies of the impacts of S. 1706 and H.R. 4829 on coal production indicate that there would be major displacement of production within the ARMS Region, and the East would lose substantial annual coal production to the West. A study by ICF for the Edison Electric Institute on the impacts of S. 1706 estimates that in 1990 coal production in northern Appalachia would be 42 million tons less than under current regulations; midwestern production would decrease 63 million tons; and Alabama production would fall by 4 million tons. While some of these losses would be displaced to central Appalachia, 54 million tons of eastern U.S. coal production would be completely lost. The ICF estimates are based on the assumptions that electric utilities in each state would achieve the reductions by the least cost method of either fuel switching, coal washing, scrubbing, or emission dispatch, including early plant retirement.

Peabody Coal Company estimated the impacts of S. 1706 on coal production using the assumption that all emission reductions would be achieved by fuel switching. Under this assumption, Peabody estimated that some 243,000,000 tons of coal production would be displaced in 1990 from 1 state to another or to distant areas within states[2]. According to the Peabody study, eastern production losses to the West would total

109 million tons in 1990. Under neither the ICF nor Peabody assumptions would the New England states suffer losses in coal production. However, coal production displacement in only 7 of the 31 ARMS Region states would account for 75% of the total displacement caused by the bill.

Employment Displacement and Losses

A major result of coal production displacement and losses would be associated employment dislocations and losses. Unemployment would occur not only among coal miners, but also among the non-mining industries that support mining and whose employment is induced by mining. Even though coal production lost in one area may be relocated in another state or region within a state, history has shown that unemployed miners will not move to distant areas where production might increase.

Applying U.S. Department of Energy productivity estimates to Peabody's estimated coal production displacement, the mining jobs lost as a result of S. 1706 would total approximately 75,000[3]. Using U.S. Department of Commerce figures, it can be estimated that the associated, indirect jobs lost as a result of the legislation would be 3 times the direct mining job losses in an average eastern and midwestern coal producing state[4]. Indirect job losses would then approach 225,000, and total job losses as a result of S. 1706 would total approximately 300,000[5]. Ninety-one percent (91%) of both the mining and non-mining losses would occur in the 7 states that would experience most of the coal production displacement. Each of these 7 states had January 1982 unemployment rates exceeding 10%, according to U.S. Department of Energy statistics. No job losses are expected to occur in New England as a result of S. 1706.

Personal Income Displacement and Losses

According to the UMWA, estimated losses in employee earnings for both miners and non-miners that would occur under S. 1706 would be $6.6 billion annually by 1990 (in March 1981 dollars). Coal miner earning losses would total $2.3 billion annually, and non-miner earning losses would be about $4.3 billion because of coal production displacement. Seven (7) states out of the 31-state area would suffer 92% of the miner earning losses and 88% of the indirect earning losses[6]. No earning losses are expected to occur in the New England states.

Total Cost of Fulfilling S. 1706

The Edison Electric Institute/ICF study estimated the increase in 1990 annualized costs of electricity production because of S. 1706 to be approximately $6.9 billion annually (in January 1982 dollars) without interstate trading of emissions. Interstate trading is unlikely because of transaction constraints between regulatory commissions and between the utilities themselves. The initial capital cost for compliance with the legislation is estimated at $26 billion. The Edison Electric Institute/ICF estimate may be lower than what would actually be experienced because the computations assumed that the emitting source would always use the least cost method of reducing emissions. No consideration was given to capital availability constraints, political constraints, and other transaction constraints. The state breakdowns of the Edison Electric Institute/ICF study show that 65% of the total cost of S. 1706 would be borne by 8 states, and that 9 states would experience average electricity rate increases exceeding 10%. The average increase in electricity rates in New England would be less than 1%.

In response to an Edison Electric Institute survey, 7 electric utilities estimated their annual electric rate increases as a result of S. 1706[7]. The results were as follows:

Utility	Annual Percent Increase in Rates	Number of Customers
American Electric Power	63	2,250,000
Cincinnati Gas and Electric	18	500,000
Central Illinois Public Service	18	305,000
Illinois Power	17	520,000
Ohio Edison	40	835,000
Wisconsin Electric Power	20	805,000
Wisconsin Power and Light	12	295,000

While similar figures for all respondents were not immediately available, American Electric Power put its annual total rate charges increase at over $2 billion. The American Electric Power figure lends support to the belief that the ICF estimates of the total cost of S. 1706 might be too low.

Footnotes

[1] see Attachment 1 for a complete list of state-required reductions

[2] see Attachment 2 for a complete list of state coal production displacement

[3] see Attachment 2

[4] the coal industry indirect job loss multiplier was based upon the same figure for Ohio of 3.3 and was rounded to 3.0. The U.S. Department of Commerce considered Ohio to be an average coal producing state in terms of its economic infrastructure

[5] see Attachment 2 for a complete list of mining and non-mining job displacement

[6] see Attachment 3 for a state-by-state analysis

[7] all electric utilities in the 31-state region were surveyed

3/82

ATTACHMENT 1

Table 4

Comparison Between Mitchell and Moynihan Bills Eastern U.S. Sulfur Dioxide Emissions, (10^3 Tons)

State	Current Sulfur Dioxide Emissions	Mitchell Bill Percent Below Current Emissions	Moynihan Bill Percent Below Current Emissions
Alabama	739.8	41.0	29.3
Arkansas	78.9	4.8	4.8
Connecticut	149.1	0.3	0.3
Delaware	90.8	18.7	0.0
District of Columbia	44.4	0.0	0.0
Florida	933.7	36.5	29.4
Georgia	837.7	54.0	34.0
Illinois	1532.8	50.2	40.8
Indiana	2079.8	57.3	56.5
Iowa	344.3	37.4	5.9
Kentucky	1108.0	62.9	70.9
Louisiana	260.5	0.0	0.0
Maine	98.4	2.8	0.0
Maryland	330.0	33.3	0.0
Massachusetts	477.7	22.2	7.3
Michigan	931.7	25.6	11.1
Minnesota	294.0	22.8	0.0
Mississippi	196.1	37.3	28.5
Missouri	1348.6	67.6	55.6
New Hampshire	109.0	46.1	52.3
New Jersey	362.0	10.6	0.0
New York	1078.9	21.0	7.1
North Carolina	618.5	14.4	0.0
Ohio	2802.6	57.8	53.2
Pennsylvania	2165.6	40.5	35.7
Rhode Island	32.1	0.0	0.0
South Carolina	315.6	30.7	0.0
Tennessee	1086.0	62.5	70.4
Vermont	15.0	0.7	0.0
Virginia	326.7	28.4	28.4
West Virginia	1093.6	53.2	50.9
Wisconsin	618.8	49.8	8.2
TOTALS	22,500.7	44.8	36.4

Source: Office of Technology Assessment

Costs of Implementing S. 1706 in 1990*

	OTA	EEI/ICF	Peabody	UMWA
Total Annual Electric Utility Cost Increases**	$3.3-$4.1 billion	$6.9 billion	$4.0 billion	-
Total Electric Utility Capital Cost Increases	-	$26.2 billion	-	-
% Increase in Annual Emission Reduction Costs	57%-71%	-	57%	-
Coal Production Displacement	-	-	243,000,000 tons	243,000,000 tons
Production Losses in East and Midwest	-	63 MM tpy	109 MM tpy	-
Coal Miner Unemployment	-	-	75,000	89,300
Total Unemployment	-	-	300,000	-
Personal Income Losses	-	-	-	$7.0 billion
Assumptions				
Total Emission Reductions	10.0 MM tons	13.1 MM tons***	10.0 MM tons	10.0 MM tons
Interstate Emissions Trading	no-yes	no	no	no
Method of Complying	least cost	least cost	coal switching	coal switching

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* all figures in January 1982 dollars

** the American Electric Power System estimates that annual costs to its customers alone would equal about $2.1 billion

*** interprets S. 1706 to mean no emissions growth permitted fact sheet

PEABODY COAL COMPANY

THE SCIENTIFIC CASE AGAINST ACID RAIN LEGISLATION REQUIRING MAJOR REDUCTIONS IN SULFUR DIOXIDE EMISSIONS

HIGHLIGHTS

The scientific evidence indicates that the major reduction in sulfur dioxide emissions in the Midwest called for by S. 1706 and H.R. 4829 would most likely not result in a similar reduction in acid rain in the sensitive areas of the northeastern U.S. and might well not result in any measurable reduction in acid rain in those areas at all.

1. Specific source-receptor relationships cannot be established. Scientists say that it is not feasible to identify the contribution of individual sources to an area affected by acid rain.

2. There is no linear relationship between midwestern emissions and acid rain in the Northeast.

   - Wet acidic deposition at sites in the Northeast and Midwest was found not to depend on the emission levels in the regions over which the air had passed, but mainly on precipitation amount.

   - A 50% increase in SO_2 emissions in Europe over a 10-year period did not, overall, increase the wet sulfur deposition in the network studied.

   - It has been shown that, on a regional basis in Europe, the increase in sulfuric and nitric acid in the air was significantly less than the increase in SO_2 and NO_x emission rates.

   - For a given reduction in emissions it is not feasible to reliably predict a reduction in deposition or acidification on a regional basis.

3. The limiting factor in the formation of acid rain appears to be the availability of oxidizing agents, not the SO_2 concentration.

   - It has been suggested that in the eastern industrialized United States the conversion of SO_2 to sulfuric acid is significantly limited by the availability of oxidizing agents (e.g., hydrogen peroxide) and that thus the production of sulfuric acid is largely insensitive to the ambient SO_2 concentration.

- According to a recent report, only a fraction of the SO_2 and NO_x emitted is converted to acids, this fraction depends on the concentration of strong oxidants, and thus even a significant reduction in SO_2 emissions may not alleviate acid rain problems.

- The State Department's scientific Advisory Committee likewise concluded that the limiting factor in the formation of acid rain is not SO_2, but seems to be oxidizing agents.

4. Local and other non-midwestern sources appear to be a greater cause of acid rain in the Northeast than was previously believed.

   - High sulfate levels at two sites in the Northeast were found to be associated primarily with eastern source areas, not with the Midwest.

   - Local oil burning and gasoline consumption may be a significant cause of acid rain in the Northeast.

5. EPA and the Comptroller General have recognized the major uncertainties about the causes of acid rain and thus about the cures for it.

THESE FACTORS MAKE IT WHOLLY UNCERTAIN -- AND IN SOME WAYS UNLIKELY -- THAT THE COSTLY SO_2 CONTROL STRATEGY ADOPTED IN THESE BILLS WOULD MEASURABLY REDUCE ACID RAIN IN THE NORTHEAST. FURTHER INTENSIVE RESEARCH IS REQUIRED BEFORE A CONTROL STRATEGY BASED ON SCIENCE CAN BE DEVISED.

THE SCIENTIFIC CASE AGAINST ACID RAIN LEGISLATION REQUIRING MAJOR REDUCTIONS IN SULFUR DIOXIDE EMISSIONS:

Certain limited areas in the United States, particularly in the Northeast, have been identified as suffering adverse effects from "acid rain." S. 1706 and H.R. 4829 seek to protect these sensitive areas from acid rain by requiring a major reduction in emissions of sulfur dioxide (SO_2) over a 31-State region in the eastern United States. The extraordinary costs to electric utilities and electricity consumers and the massive disruptions in the coal market and in employment in the coal mining industry that would result from these bills have been documented elsewhere and will not be repeated here. Nor will this paper dwell on the many uncertainties about trends in the acidity of rainfall and about the effects of acid rain. Instead, this paper focuses on the uncertainties associated with the strategy adopted in these bills to control acid rain.

Under the bills, States with relatively high SO_2 emissions -- such as Ohio, Indiana, and several other midwestern States -- would bear the greatest burden of reducing emissions, even though they are located hundreds of miles from the environmentally sensitive areas in the Northeast. As demonstrated below, the scientific understanding of the processes that lead to acid rain is too meager to provide any assurance that such major reductions in midwestern SO_2 emissions will have an ameliorative effect upon acid rain in the sensitive regions of the Northeast. Indeed, what little understanding the scientific community possesses concerning the processes leading to acid rain suggests that the SO_2 control strategy adopted in these bills probably would not result in appreciable reductions in the acid rain experienced in these sensitive areas.

1. Source-receptor relationships cannot be established at this time. At present, there is no method by which to identify any specific source or group of sources in the Midwest or elsewhere as responsible for acid rain in the Northeast. Because this point is not seriously in dispute, it is sufficient simply to note that a group of eight distinguished scientists specializing in acid-rain research, who were asked to present their views to the House Subcommittee on Natural Resources, Agriculture Research and Environment (Committee on Science and Technology) in November 1981, agreed that "[i]dentification of the contribution of individual sources to an area affected by acid rain is not feasible; one can't identify the 'smoking gun.'" (Reported in New York Environmental News, Nov. 30, 1981, p. 2.)

2. There is no linear relationship between midwestern emissions and acid rain in the Northeast. Contrary to the assumption that changes in upwind emissions of the precursor pollutants, such as SO_2 and nitrogen oxides (NO_x), must result in similar changes in acid rain downwind, the best and most recent scientific evidence indicates that there is no such linear relationship between emissions and acidic deposition and that the occurrence and extent of

acid rain appear to be governed by factors other than the sheer magnitude of upwind emissions — e.g., the amount of precipitation, the presence and ratio of various copollutants, and other meteorological, air chemical, and in-cloud chemical factors that are not well understood.

A study by Wilson, Mohnen and Kadlecek (1980, 1982), which analyzed wet acidic deposition at sites in the Northeast and Midwest and attempted to determine the origin of the air masses contributing this deposition, found that deposition of the acids did not appear to depend on the levels of emissions in the regions over which the air mass had passed, but rather depended more than anything else on the volume of precipitation. For example, at Whiteface Mountain, New York, which is located in the Adirondack area said to be sensitive to acid rain, the wet acid deposition per centimeter of precipitation was very similar for air masses that had passed over the high-emissions areas of the Midwest and for those that had passed over the Great Lakes/Canada region, where emissions are much lower. Moreover, after normalization for precipitation amount, there was no significant west-to-east gradient in the acid deposition in the northeastern quarter of the country, which indicates further that there is no linear relationship between midwestern emissions of the precursor pollutants and wet acid deposition in the Northeast.

Similarly, Granat (1978), analyzing data from the European Atmospheric Chemistry Network, found that a 50-percent increase in sulfur emissions in Europe from 1965 to 1975 led to a corresponding increase in sulfur wet deposition in only a small fraction of the region covered by the network, with otherwise constant or decreasing deposition. Thus, in that region, which is roughly comparable in size to the eastern United States, a sizeable increase in emissions did not, overall, increase wet sulfur deposition.

Again, Rodhe et al. (1981), using a crude chemical model and European data, showed that on a regional basis the increase in the concentration of sulfuric and nitric acid in the air is significantly less than the increase in emission rates of SO_2 and NO_x. They concluded that "[w]hen dealing with a coupled chemical system like the [NO_x - SO_2-nonmethane hydrocarbon system] we have studied one may not assume a proportional dependence of concentrations on emission rates."

The eight scientists testifying to the House Subcommittee in November 1981 reached similar conclusions. They agreed that, while "[o]n a global scale, deposition is linear (i.e., what goes up comes down) . . . you may not be able to predict what comes down regionally," and that "[f]or a given reduction in emissions, it is difficult to predict a reduction in deposition or acidification." (New York Environmental News, Nov. 30, 1981, p. 3.) Similarly, in a February 16, 1982 letter to Rep. Waxman, the Congressional Office of Technology Assessment stated that it could not estimate what impact the control strategy adopted in H.R. 4829 or in other pending acid-rain bills might have upon the levels of transported pollutants or upon the effect of such pollution on the environment.

3. The limiting factor in the formation of acid rain in this nonlinear system appears to be the availability of oxidizing agents, not the ambient concentration of SO_2.

Dr. Volker Mohnen, Director of the Atmospheric Sciences Research Center in Albany, NY, has offered the following explanation for the nonlinear relationship between emissions and deposition (e.g., in a letter to EPA of March 17, 1982, in Docket No. A-81-09): Only a small fraction of the primary pollutants (e.g., SO_2) emitted into the air is converted to acidic products (e.g., sulfuric acid), and the rate of conversion is determined by the availability of "oxidizing agents" (e.g., the hydroxyl radical and hydrogen peroxide). The availability of these agents in turn depends on the concentration and interaction of the primary pollutants (including NO_x, reactive hydrocarbons, and carbon monoxide, as well as SO_2) and on other meteorological and air chemical conditions. These conditions vary over time and space, and hence the rate of conversion varies. Where the ambient concentration of SO_2 and other primary pollutants is sufficiently high, the reservoir of the oxidizing agents will be lowered as they are "used up" in the process of oxidation, and if it is not replenished fast enough, there will be more SO_2 in the air or cloud water than can be "processed" by the available oxidizing agents. This makes the airshed "chemically saturated" with respect to SO_2 and means that no matter how much SO_2 is present in the atmosphere (i.e., independent of the ambient SO_2 concentration), the production of sulfates and sulfuric acid remains almost unchanged. This situation is believed to prevail in the regions of relatively high SO_2 emissions in the eastern industrialized United States. Thus, a reduction in upwind SO_2 emissions by a particular percentage in this region would not necessarily yield a corresponding reduction in downwind wet sulfur deposition within the same region and might not yield any reduction in such deposition at all.

This conclusion is supported by the recent JASON Report on acid rain (Chamberlain et al., 1981). That report concluded that heterogeneous processes involving strong oxidants (such as hydrogen peroxide and ozone) and droplets play the most significant role in the conversion of gaseous emissions to strong acids. It stated that only a fraction of the SO_2 and NO_x emitted is converted to acids in the atmosphere and that the fraction converted appears to depend on the concentration of strong oxidants. It noted that NO_x plays a role in this process not only through direct oxidation to nitric acid but also by influencing the formation of the strong oxidants that affect the conversion of SO_2 to sulfuric acid. The report concluded that, because of the limiting influence of strong oxidants, even a significant reduction in SO_2 emissions may not alleviate the acid rain problems.

Similarly, at its meeting on January 7, 1982, the State Department's Advisory Committee on Oceans and International Environmental and Scientific Affairs concluded that "sulfur dioxide is not the limiting factor in the formation of acids, including sulfuric acid, in acid rain. The limiting factor seems to be oxidizing agents, in particular NO_x. This dictates a different strategy from that recommended by the Canadian government." (Reported by Mayer in Science (1982).)

As these assessments recognize, the large and extremely costly reduction in midwestern SO_2 emissions called for by S. 1706 and H.R. 4829 might well not produce a measurable reduction in acid rain in the Northeast.

4. Local and other non-midwestern sources appear to cause more acid rain in the Northeast than was previously believed. The substantial uncertainties regarding the effectiveness of requiring reductions in midwestern SO_2 emissions to control acid rain are increased by the recent studies indicating that midwestern sources do not have the significant influence on northeastern acid rain problems as was once assumed. Rahn (1981) used an advanced "elemental tracer" technique to identify the source areas of pollution aerosol at sites in the Northeast. In preliminary results from this study, Rahn found that at sites in Rhode Island and Massachusetts high sulfate levels were most often associated with eastern source areas, in a few cases with southeastern source areas, and least often with the Midwest. Rahn concluded that, instead of finding a predominant influence of midwestern emissions,

> "the Northeast is now seen to have a rich variety of sources and transport, a complexity that was totally unanticipated: the Sudbury [Ontario] plume can be detected after transport across the entire Northeast; the Southeast pollutes New England; the East Coast pollutes itself considerably. Ironically, the (midwestern) source that we expected to find the most easily has proven the hardest to detect."

Esposito et al. (1980) have also suggested that nearby sources in the Northeast may have a significant impact on acid rain there. These researchers concluded that "local oil burning and consumption of gasoline in automobiles may be a significant, and perhaps dominant cause of acid rain" in the Northeast. Lending further support to this hypothesis is a new study by Shaw (1982), who found that approximately 50% of the wet deposition of hydrogen and sulfate ions at a rural site in Nova Scotia was attributable to SO_2 emissions in Halifax, a city located 25 kilometers to the east.

5. EPA and the Comptroller General have recognized the present limited scientific understanding of the causes of acid rain. In commenting upon S. 1706 on October 29, 1981, Kathleen M. Bennett, EPA's Assistant Administrator for Air, Noise and Radiation, noted a number of major uncertainties in the current understanding of acid rain, including the transformation processes by which sulfur and nitrogen oxides are converted into acids in the atmosphere, the processes by which pollutants are transported in the air, and the relative impact of nearby sources as compared to distant sources. Ms. Bennett suggested that, before proceeding with the "radical new concept in pollution control" embodied in S. 1706, "we must better understand the need for and impact of" the approach adopted in that bill.

Similarly, a September 11, 1981 report of the Comptroller General recognized the wide disagreement in the scientific community on such matters as the relative rates and timing of transport, transformation, and deposition, the link between emissions in the Midwest and acid deposition in the Northeast, and the relative influence of local versus distant sources on acid rain. This report also indicates that most participants in the debate agree that the present long-range transport models used to describe transport, transformation, and deposition processes still have too many shortcomings to be used for regulatory or policy-making purposes. This assessment is shared by EPA (see, *e.g.*, 47 Fed. Reg. 10820 (Mar. 12, 1982)) and the U.S. Department of Energy (see comments of DOE Office of Energy Research on models developed for the U.S.-Canada efforts on transboundary air pollution, dated Nov. 3, 1981).

Conclusion: Need for Further Research, Not Premature and Unsupported Controls

As demonstrated above, the scientific uncertainties and complexities concerning the processes involved in producing acid rain make it wholly uncertain — and in some ways unlikely — that the costly SO_2 control strategy adopted in S. 1706 and H.R. 4829 would actually ameliorate to any appreciable extent the acid rain problems in the Northeast.*/ We need to know much more about the causes of acid rain before an effective control strategy can be devised based on science, not speculation. Until scientific research reveals answers to the most fundamental and crucial questions concerning acid rain, a control strategy for acid rain can consist of nothing more than a shot in the dark. At the present time, therefore, the approach adopted in S. 1706 and H.R. 4829 is scientifically unsupported.

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*/ It should be noted that the recent widely cited report of the National Research Council Committee on the Atmosphere and the Biosphere (National Academy of Sciences) dealing with the ecological consequences of fossil-fuel combustion recommends a reduction of 50 percent in deposited hydrogen ions to protect sensitive freshwater ecosystems. Whether or not such a reduction in deposition is necessary, it is wholly erroneous to assume that such a reduction in deposited hydrogen ions would result from an equivalent reduction in SO_2 emissions. As shown above, such a reduction in emissions in the eastern industrialized United States, particularly in the Midwest, would probably not produce a similar reduction in acidic deposition in the Northeast and might produce no measurable reduction in wet deposition in that region at all. In recognition of these uncertainties, the National Academy of Sciences has established a Committee on Transport and Transformation Chemistry in Acid Deposition to prepare a brief statement on what is currently known and not known about the physical and chemical processes relating emissions of precursor gases to wet and dry deposition of acidic substances.

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Senator **Randolph**. Mr. Chairman, I would like to quote from my statement and submit it, in its entirety, for the record.

There are assertions that West Virginia forests and streams have been damaged by acid deposition. There is also concern in West Virginia that control programs might have a negative effect on the basic coal-mining industry in our state.

Acid rain is an issue of extreme importance throughout West Virginia. I want to add it is a subject of extreme importance throughout the country. I feel we must address this matter from the standpoint of our own areas and States, and do it in an informed and responsible manner. I am sure we will do that. We have been helped by the scientific approach today. So we want to achieve a goal that I hope is constructive and helpful.

Senator **Stafford**. Thank you very much, Senator Randolph.

[Senator Randolph's statement follows:]

OPENING STATEMENT OF HON. JENNINGS RANDOLPH, U.S. SENATOR FROM THE STATE OF WEST VIRGINIA

Senator **Randolph**. Mr. Chairman, for the past year our committee has been reviewing the clean Air Act as to its provisions, its implementation, and the progress made under this important statute. This is the first such general review since 1977. Our objective has been to determine what changes, if any, are required on the basis of experience and changing conditions.

For the most part, the issues are similar to those we have addressed in the past. We are being asked to legislate, however, in one completely new area, that of acid deposition, commonly called acid rain. This is clearly one of the most controversial items on our agenda. It is one which will require extensive debate by members. These discussions should be based on facts. For that reason, Mr. Chairman, I appreciate your scheduling the scientific inquiries which the committee will conduct today and Thursday.

The questions relating to the formation, transportation, and effects of acid rain are extremely complex. There are widely differing viewpoints relating to them, and I am glad that we will heard from two groups of scientists who have extensive experience in fields related to acid rain.

Studies and reports have been prepared on acid rain questions. These are quoted by various interest groups to support their postions. It is extremely important for the members of this committee to have the opportunity to counsel with the authors of these studies and to receive testimony from others who have reviewed their findings.

It is often said that there is no consensus in the scientific community about many of the acid rain questions. One of our purposes this week is, hopefully, to take another step toward achieving, if not a consensus, at least an understanding.

I recognize that different approaches and assumptions have been employed in the conduct of the scientific studies. I hope that this week we can find some common ground on which these questions can be discussed.

We are cautioned not to adopt strict contols at this time on the ground that there is insufficient scientific knowledge on the causes and effects of acid rain. The Federal Government is conducting a 10-year study on these questions. I agree with proposals to cut this time in half to produce a report 3 years from now.

Others insist there is enough evidence and the problem is serious enough that a start must be made now to control acid rain while the accelerated scientific evaluation is completed.

Our committee has before it proposals to address the acid rain problem through reductions on sulfur emissions in a 31-State area of the Eastern part of the United States. If we adopt any of these proposals, or something similar to them, there will be extensive costs for compliance and there could be shifts in mining employment and coal production.

West Virginia is one of the Nation's largest coal producers. We have large reserves of both high-sulfur and low-sulfur coal which could be affected differently by acid rain reduction efforts.

At the same time, West Virginia is concerned about air pollution and its impact on the State and its economy. West Virginia, for instance, has both sued other States and been sued by them over questions of long-range transportation of pollutants. There are assertions that our forests and our streams have been damaged by acid deposition, but there is also concern that control programs might have a negative effect on our basic coal mining industry. In short, acid rain is an issue of extreme importance throughout West Virginia.

We must address this issue but we must address it in an informed and responsible manner. I am hopeful that these two days of scientific inquiries will enable us to achieve this goal.

Senator **Stafford**. Senator Chafee?

Senator **Chafee**. I will put my statement in the record.

Senator **Stafford**. Without objection, Senator Chafee's statement will be placed in the record.

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Mr. Chairman, I would like to make a few comments.

Over the past few years, an enormous amount of research has been committed to acid rain, and the causes and effects of this phenomenon have been hotly debated.

When I cosponsored Senator Mitchell's bill last fall, I believed then, as I believe now, that the legislation is formulated on strong scientific findings. Findings which support a large reduction of sulfur dioxide emissions in the Eastern region of our country.

I am aware that there are still differences and uncertainties within the scientific community about the causes, effects, and transport of acid rain, and I am sure we will hear many of them this morning.

But there are few, if any, uncertainties about acid rain destroying lakes and streams and fish that inhabit them. There are few, if any, uncertainties that soil, timber, and crops are being damaged by acid rain. In short, acid rain is a real problem that must be curbed before it is allowed to further damage our natural resources.

If we fail to take steps to remedy this problem now, we will permit the destruction of more natural resources that is not only costly in terms of environmental values but costly to the economy as well.

Senator **Stafford**. Senator Domenici?

Senator **Domenici**. No, Mr. Chairman. I don't have an opening statement. Thank you very much.

Senator **Stafford**. Senator Moynihan?

No statement from either gentleman.

In that event, we will go to questions. Is it agreeable we go the first round with 10 minutes for each Senator and then the second round and even a third if necessary?

All right, agreed.

Let me start with a series of brief observations to the panel, at the end of which I will ask for your reaction.

The reason that some persons pressed for this hearing was a perception that there is disagreement in the scientific community. Having listened to all of you, I am struck by the level of what appears to me to be at the present time agreement rather than disagreement, at least a consensus.

Specifically, I would be interested in knowing which of you disagree with what I perceive to be generally agreed upon propositions after listening to the panel this morning.

First, oxides of sulfur and nitrogen are transported sometimes several hundred miles.

These are being distributed to you.

Second, oxides of sulfur and nitrogen can be, and often are, transformed during their transportation into acid or acid-forming compounds.

Third, the use of so-called tall stacks, most stacks taller than 450 feet, causes the long-range transport of SO_2 and NO_x to be greater than it otherwise would be.

Fourth, air masses in the region composed of Midwestern States generally move eastward and northward into a region composed of the Adirondacks and New England.

Fifth, the conversion of oxides of sulfur and oxides of nitrogen found in air masses of Midwestern origin does in fact occur, although there may be some doubt as to whether this is at a linear or nonlinear rate.

Finally, in addition, local sources—that is, sources within 100 or 150 miles—also contribute to acid deposition.

As I say, there appears to be a consensus view of the panel, if not a unanimous view. If it is a consensus view, it leads me to believe that the appropriate response to the acid rain problem is to develop a solution which controls both local and distant sources of pollution, with some flexibility built in it.

I would invite each of you on the panel, if you care to, beginning with Dr. Barrie, to either agree or disagree with those six general propositions that I have put forward.

Dr. **Barrie**. Senator Stafford, as they stand, the point of consensus that you have just made I agree with in whole.

Senator **Stafford**. Thank you very much. Dr. Demerjian?

Dr. **Demerjian**. I agree with the six points also. The only caveat that I would add would be that it is possible that an effective strategy for controlling the higher oxidized states of nitrogen and sulfur may be more effective through a hydrocarbon control strategy, for example. But in general the statements here are quite agreeable at the present time.

[Subsequent to the hearing, Dr. Demerjian submitted the following letter:]

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 30 1982

OFFICE OF
RESEARCH AND DEVELOPMENT

Honorable Robert T. Stafford
Chairman, Committee on Environment
and Public Works
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

At the May 25, 1982, hearing on the atmospheric processes of acid deposition, the questioning of the witnesses commenced when you offered a list of statements as consensus points to which you asked if all the witnesses present agreed. After informally polling the witnesses, you identified the statements as consensus points agreed to by all the witnesses who responded.

While I responded during the hearing, I have reviewed the list of statements and have a number of additional comments to offer. While I do not wish to present an expansive discussion of the points, I do think it is important that the hearing record include a number of caveats to your statements, so that they can be viewed in the fuller scientific perspective necessary to support good decision-making.

My comments on the individual points follow in the order in which they were read into the record of the hearing. I respectfully request that this letter be included in the official record of the May 25, 1982, hearing.

Statement (1) "Oxides of sulphur and nitrogen are transported, sometimes several hundred miles."

Comment: It is widely accepted that oxides of sulfur and nitrogen can travel great distances without regard to state, regional, or international boundaries. The pathways of these emissions and any transformation products are unclear, however. The transporting potential of the atmosphere involves a number of variables including: location of the original and subsequent emissions; seasonal, climatic, and meteorological conditions; and the presence of other emissions in the atmosphere. While emissions are capable of being easily pinpointed, the fate of individual emissions cannot be as precisely traced. To the extent this statement may imply that quantitative relationships of acceptable accuracy exist to relate source emissions to receptors of acid deposition, it is misleading. In fact, the extensive uncertainties in present knowledge of the complex chemical and meteorological processes governing the source--receptor relationship and the local versus distant source contribution raises questions as to what is the most effective precursor emission to control to mitigate acid deposition.

Statement (2) "Oxides of sulphur and nitrogen can be and often are transformed during their transportation into acid or acid-forming compounds."

Comment: It is generally agreed that oxides of sulfur and nitrogen do undergo chemical transformation in the atmosphere and that the products may be acidic or acid forming compounds. A number of variables affect the rates of chemical transformation, including such complex phenomenon as the amounts of oxidants in the atmosphere. Transformations and the ultimate fate of acid deposition precursors and products are not adequately understood at this time to allow development of quantitative relationships of acceptable accuracy for linking sources and receptors. These questions and others regarding transformation must be better understood before responsible scientific judgments can be made with any accuracy.

Statement (3): "The use of so-called "tall stacks"--smokestacks taller than 450 feet--causes the long-range transport of SO_2 and NO_x to be greater than it otherwise would be."

Comment: The use of "tall stacks" was an early means of controlling local pollution problems caused by local industrial and utility activities. While it is true that tall stacks effectively remove many emissions from the immediate area of their origin, it is not clear how long the emissions remain in the atmosphere nor how far they ultimately travel before being deposited from the atmosphere.

Statement (4): "Air masses in the region composed of Midwestern States generally move eastward and northward into a region composed of the Adirondacks and New England."

Comment: As was indicated during the hearing, this generalization fails to account for certain seasonal, meteorological, or climatic variations. To the extent this statement supports a linear relationship between emissions in one region and deposition in another, it is incorrect. This statement also tends to ignore any contribution of intermediate and local emissions on deposition. This statement also implies that such air masses deposit the majority of pollutants on New England, which is not verified. Finally, this assertion fails to account for the movement of air masses from Canada into New England and the Adirondacks.

Statement (5): "The conversion of oxides of sulphur and oxides of nitrogen found in the air masses of Midwestern origin does in fact occur, although there may be some doubt as to whether this is at a linear or non-linear rate."

Comment: Again, this statement, while recognizing the uncertainty of the relationship between emissions and conversion to acidifying agents, implies a number of questionable assumptions concerning pollutant pathways and fate. A more appropriate approach would simply state that conversion occurs in air masses of any origin.

Statement (6): "In addition, local sources--that is sources within one hundred or one hundred and fifty miles-- also contribute to acid deposition."

Comment: While this statement is generally true, dependent upon factors peculiar to individual sources and their locations, we do not fully understand the extent of the contribution of local sources nor the extent of their transport or transformation. We need to understand better and quantify the relationship of local and distant sources to ultimate deposition incidents before we can effectively advise decisionmakers as they determine future courses of action.

I appreciate the opportunity to offer these comments for the purpose of clarifying the hearing record on these six assertions. If I can be of further assistance, please contact me.

Sincerely yours,

Kenneth L. Demerjian
Director,
Meteorology and Assessment Divison

Senator **Stafford**. Dr. Gould?

Dr. **Gould**. Senator, I find this an excellent summary and I agree with all six points.

Senator **Stafford**. Mr. Hicks?

Mr. **Hicks**. I also agree.

Senator **Stafford**. That is a real New England response, Mr. Hicks. Coming from somebody who sounds like he came from Australia, we are gratified.

Dr. Holmes?

Dr. **Holmes**. I concur in all of the statements, Mr. Chairman.

Senator **Stafford**. Dr. Mohnen?

Dr. **Mohnen**. I would like to make a few reservations. No. 3, the use of so-called tall stacks, this tall stacks issue has been overplayed in the past. I do not see to what degree, if any, when you say that they might be transported greater than it otherwise would be. It is a correct statement, but obviously we talk about long-range transport in atmospheric sciences over a distance of 1,000 kilometers, and then a tall or a small stack, 1,000 miles away, would in all likelihood give changes of less than 20 percent. Now, with that caveat, I agree with what you said. But it must be remembered that about a year ago the issue was tall stacks in the Midwest equals acid rain in the Northeast. If you do not go as far as saying that, then I agree with this.

No. 5, I would say that we would like to know the frequency at which it occurs. Obviously I agree with the statement that it occurs. But if you say how often per year, then I would say episodes in the Northeast over the Adirondacks, where I measured over a period of 1 year, we might have a total of five sulfur episodes that are clearly traceable. Now, the rest of the time our acid rain and our dry deposition, whatever comes down, is from local, a distance, and every source.

I would also like to remark that No. 4, your statement is correct particularly in the summertime when we are located at the back side of the Bermuda high and the moist Gulf of Mexico air pumps into the Northeast. That is a typical pattern. It is well known that in our latitudes the air moves from west to east. But as you know, as the air moves from west to east, the air circulates clockwise around the high and counterclockwise. Therefore, you see every wind direction. But in principle I think it is acceptable.

Senator **Stafford**. I might say I was a long-time pilot myself and frequently having flown from here to Vermont, going over Albany, incidentally, on the way, I am well aware of the weather patterns you encounter in a 500-mile flight.

Dr. Rahn?

Dr. **Rahn**. I would just like to reiterate what Dr. Mohnen said about point No. 4. You have chosen a primarily summer situation to discuss here, eastward and northward motions. In the wintertime, we have basically eastward and southward motions. I think we should consider both because, after all, one of the largest alleged effects of acid precipitation is in snow, in the Adirondacks. We have heard almost nothing about the conditions which give rise to acidity in snow, which I suspect may be rather different than those giving rise to acidity in the rain in the summertime.

Senator **Stafford**. Dr. Shannon?

Dr. **Shannon.** I agree with all of the statements. I happen to have done some modeling on the question Volker was talking about: How much is the difference from tall stacks compared to, say, medium stacks? I would say that it typically is on the order of a 10- to 15-percent increase in the long-range transport from a particular source, to go from, say, a 75-meter stack to a 200-meter stack.

Senator **Stafford.** Thank you very much. Dr. Oppenheimer?

Dr. **Oppenheimer.** Senator, I agree with the statement completely, and I would just like to remind the gentleman to my right that the results at Whiteface Mountain show that 70 percent of the sulfate in precipitation, or 65 percent, comes out of the Midwest sector.

Senator **Stafford.** Thank you all, gentlemen, for those comments which are helpful.

Senator Randolph, do you have questions?

Senator **Randolph.** I will not call each one, but you could indicate if there is general agreement or disagreement.

Is there general agreement, gentlemen, among you that there is an acid deposition problem?

[Witnesses nodding affirmatively.]

Senator **Randolph.** That would be a unanimous answer; is that correct?

[Witnesses nodding affirmatively.]

Senator **Randolph.** Is there general agreement that the acid deposition phenomenon, if we call it that, is related to sulfur emissions from fossil fuel burning sources?

[Witnesses nodding affirmatively.]

Senator **Randolph.** Is there unanimity on that?

[Witnesses nodding affirmatively.]

Senator **Randolph.** Thank you.

Is the problem of acid deposition at least in part a result of the transport of emissions across State and even national boundaries?

[Witnesses nodding affirmatively.]

Senator **Randolph.** Thank you.

Is it likely that some level of reduction in emissions of sulfur dioxide and oxides of nitrogen would result in some level of improvement in acid deposition?

There is a difference of opinion, as I understand. All agree except the gentleman who has raised his hand.

Dr. **Mohnen.** I might add that Newton some 200 years ago said what goes up must come down. If we look at all sulfur emissions on a global basis and all sulfur depositions on a global basis, then there is a 1-to-1 proportionality. What goes up must come down.

This is not the acid rain phenomenon, as you call it. The acid rain phenomenon typically is in the Adirondacks or in the Canadian Shield. By how much do we have to reduce the sulfur emissions in one part of the country in order to relieve the problem in another part of the country? Here the question is much, much more detailed. You cannot ask and demand a unifying answer on this problem. The further away we are from the source, probably the closer we are to proportionality.

In the regions where we have other high copollutants, including carbon monoxide, other hydrocarbons, the overall transformation need not be linear in spite of what you have heard today. There are sufficient panels that have been formed in the past 2 years by very reputable chemists, including Dr. Pitts from California, who in part chaired the last panel, who have found that the chemistry in general is more nonlinear than it is linear.

In addition to that, we have examples from Europe, as I presented in my testimony, where a 50-percent increase in European sulfur dioxide emissions did not yield an equivalent 50-percent increase in sulfate wet deposition within the area of the network, telling us that this European air shed must be somehow saturated with regard to sulfur dioxides. There is more sulfur dioxide present than can be processed.

Now, it is very crucial that you understand that issue because this is the key issue to me in atmospheric sciences acid research. If indeed, as Dr. Shannon has also indicated, models can show that in the industrialized American Continent, which includes the Northeast, a change in deposition has not taken place over the past 20 years, but has spread to areas previously not affected which now show acid distress, it shows us the transformations are at maximum in the atmosphere.

In that sense, you cannot say that a reduction in emissions in one part will yield a reduction of deposition in another part of the country. Somewhere yes; somewhere no. And the crucial issue of this hearing or of any other future hearing or of any research must be when and where and by how much do we have to reduce.

Senator **RANDOLPH**. Thank you very much, Dr. Mohnen.

Dr. Gould has a comment, I believe.

Senator **STAFFORD**. Would the distinguished Senator yield just a minute so I can set the stage for the rest of the day here?

Senator **RANDOLPH**. I have two calls I must take. You will understand. It will be on the record.

Senator **STAFFORD**. The Chair and I believe Senator Domenici now have to attend a meeting with the majority leader, which is already in progress. Senator Domenici, the Chair understands you have no questions here.

Senator **DOMENICI**. I have to leave shortly, so I thank the Chair.

Senator **STAFFORD**. The Chair would reserve to any Senators on the committee who wish the right to submit questions in writing to the panel, if that is agreeable.

It is the Chair's intention at this point to turn the presiding officer's gavel over to Senator Mitchell for the balance of the hearing this morning. Again I express appreciation to all members of the panel who have been with us.

Senator **MITCHELL** [presiding]. Thank you, Mr. Chairman.

I know Dr. Gould and Dr. Oppenheimer both wanted to make a comment following up on Dr. Mohnen's comment. Before we do that, I will say that Senator Moynihan, following their responses, has some questions. I have a very lengthy series of questions to ask of some of the witnesses. So I will defer to Senator Moynihan after this for his questioning. Then I would ask the witnesses to be prepared to stay for some substantial period of time during the questioning I intend to pursue. So now if we could have Dr. Gould comment, if he would care to comment on the question posed by Senator Randolph, and following his response Dr. Oppenheimer also.

Dr. GOULD. Yes; first of all, Dr. Mohnen has stated several times that reducing sulfur dioxide emissions need not reduce sulfur deposition downwind.

It might not reduce sulfur deposition downwind. But I would like to state for the record he has presented no evidence before this committee that reducing sulfur dioxide emissions would not reduce sulfate proportionately downwind.

Second, he has made an outrageous statement that even a 50-percent reduction in sulfur dioxide might not produce any reduction in sulfate downwind. In fact, that flies in the face of all the currently accepted scientific evidence. In fact, the experiment has been done, inadvertently, at a strike in a copper smelter in the Southwest in 1980, which reduced regional sulfur dioxide emissions by about 80 or 90 percent. The levels of sulfate in the air decreased nearly proportionately. That is between 70 to 90 percent.

Senator MITCHELL. Dr. Oppenheimer?

Dr. OPPENHEIMER. Yes; the question of so-called saturation is a reasonable question to ask. The question of the uncertainty about the relationship between emissions reductions and deposition reductions in specific local regions at specific times is also a reasonable question to pose. But there is now a number which we can associate with the question of what is the reduction in regional deposition which will occur that is averaged over the Northeast with a reduction in regional emissions averaged over the Northeast. There is a number, I know. I am familiar with it because I produced it. There is no one else who has produced such a number. [Laughter.]

The number I have produced has been subject to the usual process of peer review. All else is speculation. The numbers I have produced, which I testified to today, show there will be very substantial reductions in regional deposition following emissions reductions. If anyone has other numbers that have been subject to peer review, I would like to see them in the testimony, but I don't see them.

Second, as far as the European data, people have used that argument for a while because there was a very good and interesting paper that appeared in the literature in 1978 by Dr. Granat. However, there were two problems with the paper.

First of all, Dr. Granat showed that over the period which was studied emissions changed while deposition in the network apparently had not. However, there was a transition to tall stacks, which Dr. Granat himself mentioned and which is usually not mentioned by people who use this argument, and that a lot of the emissions which are no longer deposited in the network are therefore deposited beyond the network.

Second, if you look at a diagram which shows where the precipitation monitoring stations are, you will notice there is no correspondence particularly between regions with heavy emissions and where the receptor network is located. It would be as if we set up a network along the east coast to measure sulfur deposition or along the western shore of the Great Lakes and had no monitoring stations in Ohio, in central Pennsylvania, in New Jersey, and central New York. That is the way the European network is in correspondence to the points of emission. So I would call that European data not only less than relevant to the United States but less than useful in itself.

Senator **Mitchell**. Let's let Senator Moynihan go to his questions and then everybody will have a chance to say what they want. I will stay as long as it takes to have everybody have their say.

Senator Moynihan?

Senator **Moynihan**. Thank you, Mr. Chairman.

I was the author of the first legislation on acid precipitation with the idea of getting a cycle of research underway. I see that we succeeded to that degree, and we find one another outrageous, which is characteristic of academic endearment. But I think this has been a very rewarding encounter with well-argued differences of opinion.

The one new idea to me, which I have not encountered before, is the idea of saturation. I have a physical sense of what that might mean, but approaching a chemist's understanding of what might be involved. What do we know about that phenomenon? I ask anybody. Is it a meteorological phenomenon that certain elements will reach a density that somehow never surfaced? I don't quite know. Where does the extra So_2 go if there is a saturation point in north European air? I mean, help us with the idea. It is obviously an important idea.

Dr. **Mohnen**. I would like to read to you a statement that was prepared as part of a report entitled "Source-Receptor Relationship in Acid Precipitation" by Prof. John Cahir, James Pitts—probably one of the Nation's foremost chemists in California—Prof. John Ross, Professor Twomey, and Professor Wiesenfeld from Cornell University, addressing the question you just raised.

I would like to point out that we continuously ask for evidence for "nonlinearity." The time has long since passed that we talk about linearity. We should now talk about the degree of "nonlinearity."

> It says, similar consideration may be expected to apply to the oxidation of gaseous SO_2 to form sulfuric acid; that is, the chemistry of the source-receptor relationship involving sulfur oxides cannot in the absence of other information be assumed to be linear. Thus, one must view with concern first-cut attempts to understand the deposition of sulfur-containing materials on the basis of linear chemistry. All such linear models will predict that a 50-percent change in SO_2 emission at Source A will give a comparable 50 percent change in the sulfate deposition at a remote receptor site B, all other things being the same. This need not be the case.

You ask do we have evidence? Well, the evidence that I presented from the European network—and I wish that our European colleagues from OACD could be here because I think the insult that we heard before on their network would be greatly rejected. I think that from all the information, all single effects researchers and every single chemist learned the acid rain issue from the Europeans. We learned it from them. They were 20 years ahead of us.

Senator **Moynihan**. I wonder if Dr. Gould couldn't respond to that point. You have strong disagreement there.

Dr. **Gould**. Just one statement, Senator Moynihan, about the question of linearity. Even if the deposition of sulfate is not linear—that is, if reducing sulfur dioxide emissions does not cause a strictly proportional decrease in sulfate deposition—we can make an estimate of the minimum proportionality, and we know that if it is not exactly linear, then it is nearly linear or quasi-linear.

Second, it is not necessarily the most important question to ask, because the effects of acid rain, effects of acidity on the environment, are more than linear themselves; that is, more than proportional to the amount of acid that you add.

Senator MOYNIHAN. Could I say that I think we have gotten ourselves a little preoccupied with this term linear. I have a feeling that you are describing curve X equals Y, which is not—that is not linear regulation. There are many linear regulations. Curve linear regulations can be just as important.

For instance, what are they and not what class of mathematical concept is there.

Dr. HOLMES. Senator Moynihan, I wouldn't want to leave the committee with the impression that California chemists like Dr. Pitts believe in some sort of supply side chemistry Just let me continue from the passage Dr. Mohnen was reading.

> It is, however, important to recognize that in chemistry, more cannot be less, and one must expect that an increase in SO_2 emissions at a specific source will cause an increase in some kind of deposition somewhere.

Senator MOYNIHAN. We all agree to that. But there is still the possibility, I take it, from the saturation phenomenon, in which you would just sluff off from the area so saturated. Is that something a chemist can encounter and imagine?

Dr. BARRIE. Yes.

Dr. OPPENHEIMER. Yes; it is possible under certain special conditions in certain locales that we have some degree of saturation in the Northeast. It is conceivable. The question is, if you look over the whole year and over broad geographical areas, is that a relevant policy consideration? All I can say is that I took that question and tried to approach it in a scientific manner and tried to say OK, things are not necessarily linear. How nonlinear could they be?

To the best of my ability, I have answered that question very carefully and conservatively and come back with the answer that things are only slightly nonlinear, if at all, and that we shouldn't worry too much on average in the Northeast about making emissions reductions and having saturation stand in the way of measurable deposition reductions as far as the wet part is concerned.

Once again, when you combine all parts of the problem, we are overloaded in the Northeast with sulfur. If you cut emissions, you are going to reduce deposition somewhere. The more we study this problem, the more effects show up in regions outside of the so-called core area, the Adirondacks. That is just the tip of the iceberg. So I don't think we should overdo the saturation problem. I think it is an interesting consideration, but I don't think it is significant in any way, shape, or form.

Senator MOYNIHAN. I think I have had my time. I would like to hear the panel go on. This is good work. So far I agree with all of you.

Senator MITCHELL. Thank you, Senator Moynihan.

Senator Randolph has indicated that he also has just a few questions, so I will defer to him before beginning my questioning. Senator Randolph?

Senator **Randolph**. Thank you very much, Senator Mitchell. I know that you said everything that goes up comes down. Is that right?

Dr. **Mohnen**. Yes.

Senator **Randolph**. Did you ever try to learn to fly in a Taylor craft? You can get up, but it is extremely difficult to get down. You float about 2 feet above the runway and you wonder, are you going to come down. Of course, when I was learning to fly, I was very good on takeoffs, poor on landing. I want you to know that.

I supported the Acid Precipitation Act of 1979 introduced by Senator Moynihan, S. 1574. I tried to help so that we might have a modified version of that bill incorporated in the Energy Security Act of 1980. The interagency study group created in title 7 of that law, at Senator Moynihan's request, provided the framework for the obtaining of information and developing and implementing regulatory and nonregulatory solutions to the problem of acid rain.

There is now legislation, which I have cosponsored, to require the task force to report to the Congress by 1985—about 2½ years from today—with recommendations to alleviate acid rain problems. One panelist has mentioned that if we find a solution and begin the implementation within 5 to 10 years, most atmospheric damage can be prevented and we can avail ourselves with the proper scientific tools to cope with the deposition problem.

Now, what is the feeling of the panel on the idea of a compressed timeframe for the acid rain study? Let's say they receive $30 million a year for the next 3 years. Is there one person that would perhaps talk for all of you on this?

Senator **Mitchell**. Dr. Holmes?

Dr. **Holmes**. I am a scientist and I am, of course, all in favor of research. But as a research administrator, I don't believe in simply throwing money at problems. There is a great deal of work that remains to be done, I think, to improve our understanding of some of the processes that go on in the atmosphere. But, on the other hand, I am not convinced that we don't have enough evidence in hand already to at least begin the process of regulating.

Senator **Moynihan**. Dr. Holmes, if you would excuse me, that was a rather confluent set of negatives. Would you sort those out?

Dr. **Holmes**. Let me try to straighten it out then. I don't think the state of our knowledge is so poor that we cannot begin now to regulate. Why can't one do research and regulate at the same time? This is what we have done in Los Angeles.

Senator **Moynihan**. I see. There are two negatives in that sentence. You do think we know enough to do something.

Dr. **Holmes**. That is my opinion.

Senator **Randolph**. Go ahead, Dr. Rahn.

Dr. **Rahn**. I would like to add one small remark concerning acceleration of research. There is a limit to which one can accelerate such things. There is a certain pace, a studied or measured pace associated with the development of new ideas.

I have become impressed over the past few months with the degree of uncertainties in this field, as I mentioned earlier. To eliminate these uncertainties is going to take some time and it is going to take a lot of hard brainpower as well as experiments. There is a limit beyond which you cannot accelerate such things. I am not sure that is reached or exceeded by reducing the time scale from 10 years to 5 years. But there is a certain time scale involved here by us on the long side no matter how you cut it.

Dr. MOHNEN. Given if this country had unlimited resources, and I mean financial resources, I would say your approach, go ahead with the control strategy, whatever that is, and however wrong it may be, and however successful it may be, and gamble on this and go ahead with research side-by-side. However, I am not led to believe by listening to the evening news, irrespective of which channel I switch on, that this country does have the luxury of unlimited financial resources. Therefore, I think that traditionally a certain state of knowledge was required before a responsive, reliable control strategy was implemented. It was always said those who initiated the control strategy were reasonably certain that their action would yield a benefit in those areas that they intended to protect.

Senator MITCHELL. Are you familiar with the situation when the Clean Air Act was passed in 1970?

Dr. MOHNEN. Reasonably.

Senator MITCHELL. Do you believe the statement you have just made accurately describes the state of knowledge then vis-a-vis the state of knowledge now regarding acid rain?

Dr. MOHNEN. The question you have to ask yourself is if your district——

Senator MITCHELL. I am asking you the question.

Dr. MOHNEN. Fine; my answer is that the problems in acid rain research are quite different. Here we are talking about a 50-percent reduction of SO_2 emissions. If indeed dry deposition is not dominant, as my measurements show, in the remote areas of the Northeast, and if indeed the sulfur dioxide concentration in the Eastern United States has reached what I call the saturation level, and we do not get a 1-to-1 proportionality, then after the implementation of that technology that you called for, we will find out we still have to reduce more. Isn't it at some point sensible to look at other technologies, that the one that is called plume gas desulfurization is the improper technology because we might have to ask for 80 percent or 90 percent reduction in order to protect those sensitive areas? Then the next question is, how much time is left? This is for the next Thursday panel. How much time is left?

Senator MITCHELL. The question and answer are completely nonresponsive to the question. But I will proceed and get to that later on in my line of questioning.

Dr. OPPENHEIMER. Senator Randolph, could I respond to the question about research, please?

Senator RANDOLPH. Yes.

Dr. OPPENHEIMER. The fundamental question link that is missing in this problem, as far as I am concerned, is very detailed questions about the relationship between specific very local sources and specific fairly local receptors. It is my view that that question will not be answered very quickly even with a fairly large-scale effort.

On the other hand, it is also my view that a controls program could be instituted without an answer to that specific question since we know in general what is going on in terms of emission and deposition.

Since economics has been brought up, I want to remind the Senators at a hearing I believe before this committee just about 1 year ago there was testimony by an economist that there is already $5 billion worth of damage being sustained in the United States due to acid deposition. So if we don't act, someone is paying. Someone is paying right now. Presumably we all are, since we live in the Northeast in general. Therefore, I say that there is good reason to start a controls program now. It takes years to get these things in place. And if the research down the line shows that certain things in the program have to be adjusted, so be it. But it is time to start a controls program now.

Senator **Randolph**. There are many in the private sector, the scientific community, and in Government on each side of this control issue. They bring to me, and I am sure to others, what they say are the facts. Many have used the same computer model, prepared by ICF, Inc. The facts this model has been generating are produced with quite different variable input. It has come to my attention that ICF's estimates of coal production consequences may be understated due to the inclusion of an assumption in their model—ICF—that states existing contracts between coal producers and electric utilities would not be breached if acid rain controls were enacted.

All right. This leads me to wonder if the source-receptor relationships being discussed here are accurate? What is the comment from anyone?

Perhaps no one wishes to comment. Dr. Shannon?

Dr. **Shannon**. As I pointed out in my testimony, our accuracy depends on the situation. If we are trying to simulate a long-term average or long-term accumulation, our accuracy improves because the short-term variations of which we have limited knowledge are averaged—one rain shower has a different pH associated with it than a second rain shower, but there is some statistical average for a particular location in the country. So that if you are doing model simulations for a long period of time, your accuracy does improve.

In a sense, models and modelers are almost like hired guns in that at this time not all components within the model nor all types of output produced by a model can be rigorously evaluated. The best example of this is that we have no monitoring results for dry deposition. We do have careful field studies, but those are just for a particular point in time and a particular type of surface, a particular pollutant. Thus, there is a certain freedom, for some, anyway, to adjust some of these rates inside the model and you get different results, and people cannot prove them right or wrong because that particular item of information is not yet available.

But it really is surprising how much agreement there is among models. In the work that was done in the most recent United States-Canadian joint efforts, which some of the panelists have referred to—and admittedly all of the models were linear in the relationship between emissions and deposition—the absolute values that the models were predicting as far as what source A deposits on receptor region B varied quite a bit, but the ranking of source areas as to which ones contribute the most to specific receptor areas showed quite a bit of agreement, and there was a great variation in the types of models. So I find that encouraging.

Overall I think there is probably more agreement in models than some people emphasize in their statements.

Senator **Randolph**. I will finish in a couple minutes.

In January of this year, there were 6,686 unemployed union miners in West Virginia. There are more that are unemployed today than in January. In February, there were 92,500 people unemployed in West Virginia. That is 12.4 percent of the population. It is indicated that today it is perhaps 13, almost edging up in some areas to 14 percent.

The United Mine Workers come and talk with me, and they indicate that if Senate 1706 or 1709 were enacted, they expect 14,731 and 14,094 respectively more coal-mining industry jobs lost in the State of West Virginia. That would mean a coal work force reduction from 53,000 to 32,000 in our State. There are nine other Appalachian States which would be seriously impacted, they indicate, and 21 other States to a lesser degree.

Some of the panelists seem to think that to unequally focus on the Midwest and Appalachian regions will control acid deposition in the Northeast and Canada. Yet that might be a legislative mistake from the standpoint of West Virginia.

There are many recent accounts of lakes and streams, Senator Mitchell, in West Virginia, whose fisheries are damaged by acid rain. Is there evidence to suggest that acid deposition in the eastern mountains of West Virginia is due to powerplant emissions from the Ohio Valley, which separates us from the sister State of Ohio?

Dr. **Shannon**. I would say there is general agreement among modelers that that is true, that Ohio would contribute to the acid deposition in West Virginia.

Senator **Randolph**. Does anyone else wish to comment?

I thank you very much. Senator Mitchell, I am very grateful.

Senator **Mitchell**. Thank you, Senator Randolph.

I just want to say that I have developed a good bit of information regarding the effects on employment in coal-mining areas. I will submit for the record of this hearing in response to your question a detailed response regarding that which I might say is consistent with the rest of the hearing or provides a different picture than that which the United Mine Workers presented to you.

Senator **Randolph**. I think it is important that you present that for the hearing record. I thank you.

Senator **Mitchell**. I certainly will do that, Senator.

[See the report from the Office of Technology Assessment, p. 501.]

Senator **Mitchell**. Senator Chafee has to leave in a few minutes. He has indicated he has some questions, so I will defer to him now.

Senator **Chafee**. Thank you, Senator Mitchell.

Let me start with Dr. Shannon since he has given his views on this subject. He said in his statement that there has been no dramatic increase, I believe you said, since 1940 in acid deposition in the Northeast, based on the evidence that you have. Yet, obviously something has happened. It can't solely be due to the fact we have just become more conscious of this. Obviously the acid depositions in the Northeast and the loss of the lakes and the effects on the soil have become far more prominent in the past 5 years and prior thereto. Why is this? In previous years there must have been far more coal burned, far more sulfur dioxide going into the air.

I will start with Dr. Holmes instead.

Dr. **HOLMES**. In contrast to the atmosphere, I think the response of ecosystems and particularly aquatic ecosystems, like lakes and streams, is nonlinear. In other words, a lake, or a stream, or watershed has a certain amount of buffering capacity. It can absorb acid up to a point. But when that point is exceeded, the changes occur very rapidly; pH's drop precipitously, fish populations can no longer reproduce and die out.

Senator **CHAFEE**. In other words, what you are saying is we have just finally overloaded the circuits after 100 years of coal burning in this Nation of a far greater amount than is presently occurring.

Dr. **HOLMES**. I can't speak knowledgeably about lakes in New England, but that is what people are predicting for California and that is one of the reasons why we are so very concerned about moving ahead now. We feel that we have been able to learn from what has happened in the Northeast.

Senator **CHAFEE**. Dr. Barrie, what do you say about that? You are on the receiving end of this.

Dr. **BARRIE**. First of all, I think that the evidence supporting increased acidity in rain, the magnitude, and the area covered by this acid rain, is good and supports significant changes since the midfifties in the region of the Northeast which we are discussing.

Senator **CHAFEE**. What about you, Dr. Oppenheimer?

Dr. **OPPENHEIMER**. I want to agree with the other two previous responses. Basically what has happened in the Northeast is there has been a shift from local coal burning in, say, New York State, New Hampshire, Vermont, to less local coal burning and more coal burning for electricity production in the Midwest.

Senator **CHAFEE**. Is that so?

Dr. **OPPENHEIMER**. Yes; that is established.

Senator **CHAFEE**. It seems to me that what is doing the polluting basically are older plants. They are old because they have been there for some time.

Dr. **OPPENHEIMER**. They have been there since the fifties or early sixties, not since 1935, say. If you look at the emissions inventories which are fairly well established, emissions in New York and New England of sulfur have decreased by 40 percent or so over the last two decades, but emissions in the Midwest went up considerably. In the Southeast they went up and are still going up. In the Midwest, particularly, they have leveled off in the last 10 years or even decreased. So what has happened is there has been a shift in the last 20 years of the basic sources.

Senator **CHAFEE**. I am not sure I agree with that. Obviously I am deeply concerned about this. I am a cosponsor of Senator Mitchell's bill. I find problems here because I just don't believe that there has been an increase in the sulfur emissions in the Midwest.

Dr. **OPPENHEIMER**. Let me refer you to the document. There has been an extensive compendium of emissions put together under the memorandum of intent, which is where I get my information from, which breaks down the emissions by year, and by sector, and by State, and by region from 1940 through 1978. Those trends come right out of that breakdown, which was basically put together by

EPA. If the breakdown is wrong, then I am wrong. If the breakdown is right, then I am right.

Basically what it shows is substantial decreases in local sulfur produced in the Northeast over the last 30 years, increases in the Midwest and then a leveling off, and a continued increased in the Southeast.

Now, the effect has been that acidity or sulfates in precipitation have no changed much in the worst affected area, in the Northeast, over the last 15 or 20 years, maybe even have gone down a little in certain areas, but that regionally the area affected has simply spread out as best anyone can determine so that areas like Florida that didn't have much of an acid deposition problem 20 years ago now have a very significant problem. So there has been a stabilization and a spreading.

Senator **Chafee**. Dr. Mohnen?

Dr. **Mohnen**. The oldest record that we have in this country that I would call reliably acceptable, and whatever else you want to attach to it, is that of Prof. Eugene Likens from Cornell University. He was the one who studied with the Scandinavians in the European network and came back and did similar things that the Harvard group did. This evidence that is well quoted says we have no change in acidity over the past 25 years in the middle of the sensitive area, which is the Harvard group area.

New England has indeed experienced a 40-percent reduction in sulfur dioxide, I might say maybe less, because of the introduction of nuclear power. The Midwest has not seen an increase, as a matter of fact. Overall, the Midwest has declined. But Dr. Oppenheimer is right, the Southeast has significantly increased.

Now, the picture that seems to emerge is one that has been mentioned earlier—I forgot by whom from our panel—that indeed in the Northeast, the situation with regard to deposition, particularly hydrogen ion deposition, has leveled off and probably it has been around 4.1, 4.2 for quite some time.

Senator **Chafee**. Why are all of these lakes dying all of a sudden?

Dr. **Mohnen**. This is correctly addressed by Dr. Holmes. It is an effects problem, not an atmospheric problem. From the atmosphere we see a continuous flux coming down, mostly wet deposition flux in the Northeast of hydrogen ion sulfate and nitrate. This flux probably on the average has remained the same for quite some time. But the soil's ability, the watershed's ability, to deal with that constant flux, that is where the change has occurred.

Senator **Chafee**. Do you agree with that, Dr. Gould?

Dr. **Gould**. Senator, maybe the best example to use would be to imagine taking $100 out of the bank every year. Eventually you are going to hit rock bottom. It doesn't matter whether you take $100 each year, one after another. It would be equivalent to adding the same amount of acid to our lakes and streams every year. Eventually you hit a critical point. That is what is happening now. Acid rain is a cumulative phenomenon. The fact that the amount of acid rain we are adding every year hasn't necessarily changed dramatically doesn't mean you won't reach a dramatic endpoint. You can see that every night on television if you watch the Rolaids commercial.

Senator CHAFEE. Therefore, would it be true, if you don't reduce the amount of sulfates to zero then we will continue to lose lakes? In other words, nature has no way of combating this? It is a cumulative effect that we can't meet?

Dr. GOULD. Nature does have a way of combating it because natural systems generate buffering capacity that counteracts the acidity that is added. That will be different for each particular lake and stream.

Senator CHAFEE. If we gave a respite or reduce the saturation, it would give nature a chance?

Dr. GOULD. That is right.

Senator CHAFEE. Let me ask, we have heard a lot about the sulfates, but I believe only Dr. Holmes mentioned the NO_x and its effect. How does that figure in here? I know, Dr. Holmes, you touched on it in your California experiences. What do you say about that, Dr. Rahn?

Dr. RAHN. I am afraid I have to say that this is an area that I have never worked in specifically and would much prefer to hear Dr. Holmes' comments on the nitrogen oxides. We are an aerosol measuring group.

Senator CHAFEE. Dr. Barrie?

Dr. BARRIE. In my opening statement I did mention NO_x. I believe you weren't here. But 20 to 30 percent of the acidity in the Northeast is associated with NO_x. Our freshwater lake biologists tell us that the nitrate acidity is essentially neutralized by biota which, when they digest the nitrate ion in lake water, put out a neutralizing hydroxyline. So that we are mainly concerned with the sulfur emissions as far as fresh water lake effects. On the other hand, there are other effects, like the accumulation of nitrates in the snowpack during the winter months and the spring snowmelt shock which occurs when these pollutants are leached out very quickly. So that we should be taking nitrogen oxides into account. So I think we should consider carefully what we do with NO_x in parallel with the sulfur dioxides.

Senator CHAFEE. What is the tradeoff between mobile and stationary sources?

My time is up, is it, Mr. Chairman?

Senator MITCHELL. It is, Senator, but go right ahead with this question.

Senator CHAFEE. Let me ask Dr. Holmes about the tradeoff between what you find in California, the NO_x, primarily from mobile sources.

Dr. HOLMES. We have been finding over the last several years that about two-thirds of the acidity in rain and fog is due to nitric acid which comes from NO_x. Now, we're at a point in California where NO_x emissions are just about equally divided between mobile sources and stationary sources, so we need to look not just at mobile sources, as we have been in the past, but now begin to look to stationary sources as a place to carve out some additional reductions of NO_x emissions.

Senator CHAFEE. Thank you all, gentlemen. I want to express my appreciation, too, for each of you coming here. Now I will leave you to the tender mercies of Senator Mitchell.

Senator MITCHELL. Thank you, Senator Chafee.

I would like to begin, Dr. Rahn, by asking you some questions about your testimony here today which follows on a paper you published last November. Before I ask any questions, I want to make sure that I understand the conclusions that you have set forth today in this paper.

If I understand it, what you say is that there is some manganese and some vanadium in the emissions both in the Midwest and the East.

Dr. **Rahn**. Correct.

Senator **Mitchell**. And that there is a higher level of vanadium in the eastern emissions, which therefore produces a lower ratio of manganese to vanadium in those emissions than with respect to emissions in the Midwest.

Dr. **Rahn**. That is correct; because the concentration of manganese in each place is roughly equal.

Senator **Mitchell**. About the same. So that you took a look at some particular filter samples in the East and you measured the ratio of manganese to vanadium, believing that a high ratio of manganese to vanadium would support the conclusion that it comes from the midwestern source and that a lower ratio of manganese to vanadium would support the conclusion that it comes from an eastern source; is that correct?

Dr. **Rahn**. Correct.

Senator **Mitchell**. Now, obviously fundamental to your conclusion, and something which you have recognized in your statement today, is the rate of deposition of the various materials being measured—manganese, vanadium, and sulfate. Implicit in your conclusion is the assumption that manganese, vanadium, and sulfate deposited out of the air at the same rate as the air mass travels west to east, or as you say in your paper: "Acknowledging that problem, differences in deposition of manganese and vanadium would not be expected to be larger than a factor of two to three during transport."

Have I accurately described the problem and what your response is to it?

Dr. **Rahn**. Yes.

Senator **Mitchell**. Now I ask that because you have cited no evidence to support your estimate of a rate of deposition of manganese two to three times greater, or your exact words, "would not be expected to be larger than a factor of two to three."

First I would like to ask you whether or not it is true that the size of the particles has a bearing on the rate at which the materials are deposited out.

Dr. **Rahn**. It does within certain limitations.

Senator **Mitchell**. I will read you a statement now that comes from an article published in Science magazine just a few weeks ago. It says, and I quote: "Particle- associated metals characterized by larger mass median diameters exhibited higher deposition velocities." You would generally agree with that statement?

Dr. **Rahn**. Within certain limits. It depends on the sizes of the mass median diameters we are talking about here.

Senator **Mitchell**. Isn't it also true that vanadium is generally found in smaller particle sizes than manganese?

Dr. **Rahn**. In general. But I wish I had better data for the East than I have at my disposal right now. We have found, to our great surprise, around the Northeast, both in Rhode Island and New York, essentially identical mass median diameters for manganese and vanadium. This is in some contrast to what we had found earlier in the European arena. There is a clear need for further data, and this is something we ourselves intend to get into in the near future, particularly from the Midwest. I have gone through the data on size distribution from the Midwest, with which I am familiar. It is a little depressing to see that there is relatively little of it there that is sound enough, general enough that I can use it for considering how much elemental ratios, such as manganese to vanadium, might change during transport from the Midwest to the Northeast. I have tried to simulate this based on New York aerosol and based on aerosol from Europe that we measured, that we ourselves measured some years ago, and have concluded on that basis that one might, using a simplified model of removal—and again, I hate to keep coming back to it, but there are many fewer data out there to draw on. You would be surprised how few studies of metal deposition there are, and in particular those which include data on vanadium, that you can find. There is quite a bit on manganese, but relatively little on vanadium. I have estimated factors of two or three in and around Europe. Between Europe and the Arctic we have observed factors of three to four in the change of this ratio. Between the Midwest and Northeast we have roughly one order of magnitude difference in the manganese and vanadium ratio to begin with. I don't expect to see anywhere near that large change of ratio during transport to obscure the effect of those two regions. That is the best I can say now.

Senator **Mitchell**. Let me ask you about another statement.

> Vanadium is always found at somewhat smaller particle sizes in the aerosol than is manganese, so that preferential removal of the large particles during transport should decrease the manganese-vanadium ratios.

Do you recognize that statement?

Dr. **Rahn**. I can't but agree with that statement, sir.

Senator **Mitchell**. Because you wrote it.

Dr. **Rahn**. That is right.

Senator **Mitchell**. So the fact of the matter is, of course, that if your expectation, and you have acknowledged it is nothing more than that, that the rate of deposition out of manganese above that of vanadium is, in fact, much higher than that, then the entire theory upon which your conclusion is based is rendered invalid, is it not?

Dr. **Rahn**. No, not necessarily. We are talking about numbers here, not yeses or noes. We have an order of magnitude difference that would have to be obscured before the Midwest could be confused with the East. We are talking about maximum changes during true long-range transport, and I stress that what we have observed in the Arctic, from Europe to the Arctic, is several times longer in distance than what we are talking about here. We are talking about well over 1,000 miles in the Arctic case and something like 600 miles maximum in this case.

Senator **Mitchell**. Let me amend that to say then to the extent that the rate of deposition of manganese exceeded that of vanadium, as that increased, as the rate of differential increased, the less valid becomes the conclusion that you have reached.

Dr. **Rahn**. That is true. But the difference in removal rate you would have to see is far beyond anything that would be expected. We are going to try to demonstrate and measure it one way or the other.

Senator **Mitchell**. I want to get to that now. There have been some studies on that that reach conclusions quite contrary to what you indicated you expect. Are you familiar with the work done on the vanadium deposition rate by P. A. Koskey in 1976?

Dr. **Rahn**. I think you are referring to one of a series of studies coming from Harwell in England—on British aerosol.

Senator **Mitchell**. That is right; I will just cite some further studies here. This is a matter of public information. This is a paper on the United States-Canadian Memorandum of Intent. There have been works on sulfate deposition by Garland, Droppin, and Sebering, and also the Science magazine article to which I just referred, which was published just very recently by Lindberg.

If you take all of those studies, review them, you reach the conclusion that the rate of deposition of manganese is at least 10 to 20 times faster than the rate of deposition for vanadium and sulfate.

Let me finish.

If that is true, then it seems to me that the assumptions underlying your conclusion are invalid, either wholly or in large part, and that in fact all you are doing is measuring the residue that has come from the Midwest. And naturally the larger particles, manganese, fall out of the air during the transport.

Dr. **Rahn**. We come to a small problem of jargon and language here. If you will recall, throughout each of my statements and in the published articles on atmospheric environment and on this we have stated at the beginning of each article we will agree to a colloquial use of the word manganese to represent something that is not total manganese, that is noncrustal, but submicron manganese. In all of my statements, the manganese-vanadium ratio, for example, is actually noncrustal manganese to noncrustal vanadium. That means we are attempting to subtract out the coarse particle component of manganese and the coarse particle component of vanadium.

I believe that the study of Lindberg and a number of these studies in England are referring to total manganese and total vanadium. There I agree with you completely, total manganese is a coarser particle size than total vanadium. There is no question about that.

We subtract out—for example, around the Northeast—roughly half the total manganese is crustal, but something like only one-tenth or one-twentieth of the total vanadium is crustal. So you are comparing apples and oranges here.

We would then have to go back to each one of those other studies and transform from manganese to noncrustal manganese and from vanadium to noncrustal vanadium in order to compare their results with what I am proposing here. I think when you do that you will find out that this is an area that is clearly in need of more work. There is no question about that. But I think that that will remove the greater part of any discrepancy just by that simple act.

Senator MITCHELL. Nobody disputes the need for more study. But I would just say that I believe the information now available in the literature indicates that from the data you have presented, an alternate conclusion, which is diametrically opposite to yours, is just as reasonable as the conclusion you have reached. That is, as Midwestern sulfur emissions travel eastward, the manganese which was initially present decreases rapidly relative to vanadium, so by the time the pollution reaches the east coast, the manganese-to-vanadium ratio is not distinguishable from the ratio the Eastern source would produce.

Dr. RAHN. I have to respectfully totally disagree with that for reasons I have given.

I would also like to add, for the record, the role of manganese in this whole thing has been questioned. We do not live or die with manganese. It happens to be an element we have a lot of information on and so we use it.

In the High Point, N.J. studies in 1976 and 1977, we had data on a wide variety of trace elements in addition to manganese and vanadium. I have attempted to substitute, for example, the elements arsenic and selenium, so we have arsenic to vanadium ratios and selenium to vanadium ratios. When you do that, arsenic is a little noisy, for reasons I don't understand, but selenium, which has also been produced, is a very good indicator of coal. Whether it is or isn't I am not quite sure. That behavior of that ratio in High Piont, selenium and vanadium compared to manganese and vanadium, the answer you get about where the air mass has come from is exactly the same. You get the same number of samples classified from the Midwest and from the East.

The thing about selenium is it has no crustal components. All of the arguments you have just given me about coarse particles of manganese falling out do not apply in the case of selenium. These are, unfortunately, inaccurate arguments that are floating around here. They simply don't apply.

Senator MITCHELL. It is a matter of some dispute, of course, as to whose argument is inaccurate.

Now I want to discuss one other aspect of your conclusions alongside those of Dr. Mohnen's. You both have been vigorous proponents of the argument that we ought not to do anything now because we don't know enough about it. One of the conclusions you reach in your statement, and I am going to quote now.

> A 31-State regulatory region for acid precipitation may be too large. According to our data, the prevalent distance scale at least for pollution aerosol is roughly 200 miles.

That is the statement.

Dr. RAHN. On page 4.

Senator MITCHELL. Dr. Mohnen, on the other hand, relied very extensively and vigorously upon Dr. Granat's studies in Europe, which appear at pages 9 through 11 or 12 of his statement. And you argue, Dr. Mohnen, that in Europe, there were increased sulfur emissions, but there was no increase in deposition within the areas covered by the network. You then quoted from Dr. Granat's work, which said, "The probable answer is that increasing amounts of sulfur have been deposited in areas not covered by the network, probably eastward of major sulfur emission areas."

In other words, if I understand what Dr. Granat said, and you have vigorously defended his study here, it is that the increase in emissions in the European area was not felt in the monitored area because they went way over the monitored area and passed eastward of that region. Since the area involved is several hundred miles, the network area involved, you are saying that we shouldn't pass this bill because it doesn't cover the problem. The precipitation goes way over that region.

On the other hand, Dr. Rahn sits here and says we shouldn't pass this bill because it doesn't cover the problem. It only goes 150 to 200 miles.

I would like to ask you both if you would comment on that.

Dr. **Mohnen**. Who should start first?

Senator **Mitchell**. Take your pick.

Dr. **Mohnen**. Thank you.

When we talk about the Granat work, it refers to wet deposition, what comes down with rain. When we talk about the work that Dr. Rahn talks about, it is particles. Manganese and vanadium are particles, and sulfates that he refers to are the so-called fine particulate matter that arise either at the primary emissions, which can be substantial near sources, in the wintertime, as we heard from Dr. Shannon, or these are minute sulfuric acid droplets that are formed in the atmosphere by gas particle conversion.

Now overall, about 10 percent of the sulfur dioxide that leaves any area or that is emitted into the atmosphere ends up as a sulfate, sulfuric acid aerosol as a particle. This is the domain that Dr. Rahn talks about, and his work is mainly in the area of aerosols. It has nothing to do with rain. Dr. Rahn has never seen a rain sample.

Dr. **Rahn**. I have seen them. I haven't analyzed them.

Senator **Mitchell**. Let me interrupt there and ask this question. What you are saying is that Dr. Rahn's studies have been limited to what is 10 percent of the problem. That is what you just said, isn't it?

Dr. **Mohnen**. That is correct.

Senator **Mitchell**. Then I would like to ask you, Dr. Rahn, how you can make such a strong recommendation for no action when your studies have limited themselves to 10 percent of the problem and ignored 90 percent of the problem. Would it not make more sense to look at 90 percent of the problem and make a recommendation based on that?

Dr. **Mohnen**. We are doing that, and I tried to give the answer on that.

Senator **Mitchell**. Let's let Dr. Rahn answer.

Dr. **Rahn**. In the spirit of first things first and one step at a time and walk before you can run and all of this sort of thing, we are proceeding along that sequence in our laboratory. I would like to repeat what is in this statement submitted today as well, that the statement of last November which has caused such a fuss is a result of spare time and effort. It is the result of not large amounts of effort on our part. It is something which is a spinoff of another study. We have not to date had the luxury of going into the detail of examining all aspects of this problem.

Senator **Mitchell**. Which makes the intensity of your recommendation all the more baffling. Not only is it limited to 10 percent of the problem, it is spare time work done as a spinoff of something else.

Dr. **Rahn**. All this is true, of course, but what makes it perhaps not so baffling or the way I justify it is the discrepancy that I found in the atmospheric system or that I seem to have found in the atmospheric system based on these new measurements relative to what I thought I was going to find when I looked into this. If I have suffered such a reversal of opinion in my little corner of this, what is liable to be found in other corners of this whole problem?

This is a philosophical statement. I know it is not really possible to extrapolate from my aspect of this to other aspects of this. But I have found quite a different atmospheric situation in the Northeast from what I expected to find.

Since there are two questions actually to me at this point, may I go back——

Senator **Mitchell**. I just want to interject at this point I find it incredible that on the basis of admitted part-time, spare time study, as a spinoff of something else, in an area that you had no previous experience with, that involves 10 percent of the problem, you come in here and make a very emphatic and specific recommendation, "Here is what we should do. Here is what we shouldn't do." It just strikes me that the level of the recommendation bears no relationship to the effort that went into the studies and the studies themselves that support it.

Dr. **Rahn**. Part-time studies don't have to necessarily give wrong answers. They might be right, you know.

Senator **Mitchell**. That is true. They might also be wrong.

Dr. **Rahn**. May I go back to the other question that was essentially—what I would like to clear up or answer in a little detail is the relationship between long-range transport, or lack of it, and short-range transport, or lack of it, as shown by our work around Rhode Island and other parts of the Northeast.

It has been interpreted, and I think wrongly so, that this work shows, or at least is alleged to show, there is no long-range transport. That is not right. It clearly shows a lot of transport. It shows transport on all scales, from the nearest sources to sources up to 150 miles to sources over 150 miles.

We have in our laboratory for the first time actually demonstrated the existence of long-range transport on the scale of 600 miles in a direct fashion. I don't think this has been done by other techniques. The question is, though, the relationship between long-range transport and the shorter scales of transport.

If you were, for example, to remove emissions in the entire Northeast, of course you would see considerable amounts of sulfate in the atmosphere coming from the Midwest. I believe in long-range transport. I have seen it in other regions of the world. My experience in various remote regions is if you have the proper tools to see it, you will find it. It is going on. As stated in here, I believe it is more common and widespread than is recognized today, after a decade of increasing awareness on this problem. But is that all there is to this story in the Northeast? That is what I have set about to try to answer here.

Senator MITCHELL. Do you know of anybody who has ever suggested that?

Dr. RAHN. No.

Senator MITCHELL. Has anybody, to your knowledge, ever suggested that all of the deposition in the Northeast or East comes from the Midwest?

Dr. RAHN. Practically all of the popularized accounts, the thing that is in the heads of most Americans in the Northeast, I believe, rightly or wrongly so, is that the Midwest is like a monolith. It spreads its aerosol over the Northeast and——

Senator MITCHELL. What do you base that on?

Dr. RAHN. I base that on many, many, many statements in the media, in the popular press, on basically listening to everyone else.

Senator MITCHELL. I just want to say, Dr. Rahn, I have discussed this subject hundreds of times in the East—hundreds of times—before literally thousands of people, and I have never heard anybody make the statement that you now say everybody in the East believes, that it all comes from the Midwest. We have been very careful, those of us who have been proponents, to make clear that this is a regional problem and that the sources are regionwide. Dr. Barrie has cited the statistics here today.

That leads me to another question. Both you and Dr. Mohnen have repeatedly used the phrase of making one area do something to benefit another. Dr. Mohnen, I tried to write your words down. I don't think I got them exactly. You said the real question here is how much do we have to reduce in one part of the country to relieve a problem in another part of the country.

Now I want to ask you, have you read my bill, S. 1706?

Dr. MOHNEN. Yes.

Senator MITCHELL. Have you read it, Dr. Rahn?

Dr. RAHN. Parts of it.

Senator MITCHELL. Parts of it?

Dr. RAHN. Parts of it.

Senator MITCHELL. But you come in here and recommend strongly against a bill you haven't even read in full; is that right?

Dr. RAHN. That is correct.

Senator MITCHELL. I would like to have either of you tell me where it says that my bill applies only to the Midwest.

Dr. RAHN. Of course it doesn't. I understand that. We both understand that.

Senator MITCHELL. It applies in every single one of the 31 States in the region. Even if your theory is correct, Dr. Rahn—let's assume it is correct--all it means is that the acid deposition is falling within 200 miles of the source, rather than 600 miles of the source. Does it have a less harmful effect there? Isn't that addressed by my bill?

Dr. RAHN. The question is your bill sets a single standard of emission for the large sources. I believe it is 1.2 pounds per billion Btu's.

Senator MITCHELL. That standard is now in the law.

Dr. RAHN. OK. All right.

Senator MITCHELL. It is for all new facilities.

Dr. RAHN. My concern is this, that when you look at which areas are going to be affected most in terms of reduction in emissions, it is the so-called High River Valley, it is the Midwest, where the percentage of reduction of emissions may be—if I remember figures slightly incorrectly, forgive me—on the order of 40 to 50 percent reductions; whereas, in the Eastern States one may have reductions on the order of, I don't know, a few percent, let's say 10 percent or less.

Senator MITCHELL. But that isn't applied anymore. If you want to stop something, if there are eight or nine of you at the table and we want to stop a certain action, we have to stop those who are doing the action, if we want to stop the action.

Dr. RAHN. But the question is stopping it from where. If emissions are reduced mostly in the Midwest, then the question is where are you going to see those effects?

The philosophical underpinning of this bill, and any of those others that involve large regions of this, is there is a single atmospheric system here and you will reduce emissions, how shall I say it—one goes after or one reduces in the largest sources in the entire region first and somehow that one expects to feel equivalent or nearly equivalent effects over this entire region.

From what we have turned up, the smallest scale regionality of transport, which, by the way, is supported by other independent studies, I believe, such as the EPA SURE study, for example, one would see widely divergent effects in different potential downwind receptor regions. For example, if the acidity in the Northeast is, as I believe—cannot prove, but believe—is largely due to Northeastern emissions, if one would reduce emissions in the Midwest by 40 or 50 percent, whatever, one may have only very small changes in deposition of acidity or acidity in the atmosphere in the Northeast.

Senator MITCHELL. But it would have a great reduction in the Midwest, would it; not?

Dr. RAHN. It would have a great emission in the Midwest.

Senator MITCHELL. A great reduction in deposition.

Dr. RAHN. In those regions affected by the Midwestern aerosol, which I submit are not fully known yet.

Senator MITCHELL. Wait. Everybody here, including Dr. Mohnen, has said what goes up must come down.

Dr. RAHN. But the question is where and when.

Senator MITCHELL. But what you are saying is the emissions from the Midwest don't come down in the East; they come down within 200 miles of where they are emitted. That is what you said.

Dr. RAHN. Yes.

Senator MITCHELL. 150 to 200 miles, roughly.

Dr. RAHN. I am trying to express a complex thing in a single sentence here. This is a rough average figure.

Senator MITCHELL. But my point is aren't the people of Ohio and Pennsylvania and Illinois entitled to an acid-free atmosphere just as much as the people of Maine, New Hampshire, and Vermont?

Dr. RAHN. They are entitled to an acid-free environment. I can't dispute that.

Senator MITCHELL. What is wrong with saying they have to clean up not just for the sake of the people of Maine and Rhode Island but the people in New York and Pennsylvania as well?

Dr. **Rahn**. The point is you may not get the effects you expect at all. I think that people expect that by cutting down the sources in the Midwest so tremendously that you are going to see large reductions in the acidity in the Northeast.

Senator **Mitchell**. Just a minute. You just said if you want to reduce deposition in the East, you have to reduce emissions in the East.

Dr. **Rahn**. That is correct.

Senator **Mitchell**. Now you are saying if you reduce emissions in the Midwest, you won't get a reduction in emissions in the Midwest?

Dr. **Rahn**. You are reducing in the Midwest by let's say 40 or 50-Percent, or something, and you would reduce in the East by under 10-percent. It should be clearly stated that this may give a reduction in deposition of acidity in the East, along the east coast—for example, regions that I would consider to be under the influence of Northeastern sources—by very slight amounts. I don't think that is the general perception of what is going to happen.

Senator **Mitchell**. Just a minute. You just said a reduction of 10 percent emissions in the East would produce a reduction of emissions in the East. Yet you are saying a 50-percent reduction in the Midwest would not produce a reduction in emissions in the Midwest. How can you make those statements?

Dr. **Rahn**. I didn't intend to say that. If I did, I am sorry. If one reduces in the Midwest, if one reduces emissions in the Midwest, there will be some kind of reduction in the Midwest.

Senator **Mitchell**. What is wrong with that?

Dr. **Rahn**. Nothing is wrong with that. I never said anything is wrong with that. But you will affect different parts of this 31-State region I think tremendously differently. I am not sure that is appreciated by most of the public at this point.

Suppose you changed by only 5 or 10 percent the deposition of acidity in half of the Northeast. Let's take a figure. I don't know whether that is right or not. Whereas you have gone through these billions of dollars to reduce Midwestern sources. That is I think an unexpected lack of effect. That is what I am concerned about.

Senator **Mitchell**. What you are saying is that the deposition is relatively local, not long range, and then you are assessing only the long-range benefits against the cost. What I am saying is even assuming the validity of your thesis, which I do not frankly believe, but even assuming it, that you must take the benefits throughout the entire region from the reduction and then measure it against a cost, not just the benefits from the area that is not affected.

Dr. **Rahn**. My point is the benefits aren't distributed equally over the region at all. They are distributed less equally than I thought going into the situation 9 months ago and I suspect that a lot of other people think even now.

Senator **Mitchell**. Well, Dr. Mohnen, I interrupted you in the middle of an answer, for which I apologize. If you could even remember where we were.

Dr. **Mohnen**. I hate to tell you, but I forgot your question and I forgot the answer.

Senator **Mitchell**. Let me go on.

Dr. Mohnen, you have testified that there is no linear relationship between emissions and wet deposition based upon your analysis of the depositions at Whiteface Mountain; is that correct?

Dr. MOHNEN. Whiteface Mountain; Champaign, Ill.; and all stations in between.

Senator MITCHELL. Then I want to ask you, if the relationship is not linear, have you calculated the relationship? Is there a relationship?

Dr. MOHNEN. The question is rather difficult to answer. As I said before, what goes up must somewhere come down. So if we would say that your bill to the benefit of mankind will reduce global deposition of sulfur, then I would say for a 50-percent reduction that your bill calls for you will obtain on this spaceship Earth a 50-percent reduction without any question in whatever form. It can come down with the rain. It can come down with Dr. Rahn's aerosol. Or it can come down as sulfur dioxide hitting the ground and being absorbed and reworked by the vegetation.

The question I addressed and the point that bothered me terribly was the following, that we have a region that I call the eastern industrialized U.S. that is rather moderately polluted at its core with hydrocarbons, NO_x, sulfur dioxide, and other things, in that air mixture. When this air mixture has been processed by clouds, clouds then making rain, we suddenly find that the determining factor on how much acid rain comes down really isn't the amount of sulfur dioxide in the air but it is governed by substances such as hydrogen peroxide. It is governed even by substances we haven't yet discovered. So what it boils down to is that the calculation of such rather complex systems still awaits future completion.

What we have at the present time is a very good linear chemistry. All models assume this linear chemistry. That is the first step. This is what you would use to do a diagnostic test. But when you try now to use those linear models to predict consequences of legislated action or control action, then suddenly you realize you really should not use those linear models. You should be a bit closer to reality, which is nonlinear models.

The very first nonlinear model I ran across was many years ago in Sweden with Dr. Crutzen and Dr. Rodhe. They worked with a group that published a paper just about a year ago. Now, that model contains 19 equations that are what we call coupled, so that every molecule reacts with every other molecule to simulate a real atmosphere. This is what we call a coupled system.

Now, out of this coupled system comes nonlinearity. The very first answer that this nonlinear model tells us, not even with respect to acid rain, but just with the overall chemistry transformation, is that we must be very cautious in how we go about reducing. For example, if we reduce $S0_2$ and NO_x, then at some point downwind of the emission sources, where the ratio is appropriate, where we also have hydrocarbons, we might experience an increase in ozone. In another distance we might see another change relative to each other. So the system that we sense is complex, complicated, and at this time, beginning to be formulated. We cannot take at this time an answer that the Rodhe model gives us and run with it. That is why in my testimony I say time and again we might, we should, be very careful. I am saying that the state of nonlinear models is in its infancy. People are looking at it. The Canadian colleagues are looking at nonlinear models. In this country companies as well as scientists are looking at nonlinear models. Eventually we will see how nonlinear a system really is. So please don't argue on the basis that we don't yet know the degree of nonlinearity. I am just saying watch out. We might get a black eye when we focus on reduction of one component only, just SO_2, and then allow, on the other hand, $N0_x$ and hydrocarbon to go up or down. We don't know yet the result of such changes, and out of this could come—could come—a situation where we say gosh, had we known, we would have done it slightly different.

Senator **Mitchell**. I just say, Dr. Mohnen, that that argument that we have to wait until we have the complete answer to every part of the problem is the argument most used by people who want inaction, want no action. And were we to wait for that day, it will be your grandson and my grandson who will be discussing the issue then. Human affairs do not lend themselves, and never have lent themselves, to the approach that you have to have a precise scientific answer to every conceivable question that exists before you take any legislative action. That is the point I made earlier with respect to the Clean Air Act. The fact of the matter is we know much more now about acid rain than was known about the subject matter of the Clean Air Act when it was passed in 1970. We have had to make some modifications. But I don't think there is a person at this table, I don't think there is a person in this room, I don't think there is a person in this country who thinks we ought to repeal the Clean Air Act because of that. The arguments being made now are identical to the arguments made then.

Let me ask Dr. Gould to respond. He is shaking his head.

Dr. **Gould**. Thank you, Senator, but I have no comment.

Senator **Mitchell**. Dr. Oppenheimer, did you want to comment?

Dr. **Mohnen**. May I respond to your statement, Senator?

Senator **Mitchell**. Let me let someone else get a word in. Yes, you can say anything you want.

Dr. **Oppenheimer**. Following Volker's prescription, after some very interesting and stimulating conversations, I set out to construct a simple nonlinear model and assume that the response was nonlinear and try to determine how nonlinear it could be. As I have said, the results which I have drawn so far and which are conservatively drawn, attempting to make the system as nonlinear as possible, suggest strongly that regionally the entire system which produces wet sulfur deposition is barely nonlinear, as I testified and put specific numbers to.

Let me also say that the Rodhe model which appeared in the literature a year ago and which has some problems with it has now been applied to the Northeast by Perry Samson, University of Michigan, and it has limitations. It is not the final result, but Perry's model shows coincidentally that a 50 percent emissions reduction will yield nearly a 40 percent reduction in wet sulfur, identical to what I said.

Now, these are not the last word on the subject. They do represent the cutting edge of what the state of knowledge is today.

I will also say on the question of NO_x, the effect of NO_x, the JASON report which Volker mentioned a little while ago——

Senator **Mitchell**. I want to interrupt and say Dr. Mohnen, you should know that the same people who oppose my acid rain bill want to relax the standards for emissions of nitrogen oxide, to increase those emissions, the very same people, in this administration, who Dr. Demerjian represents. [Laughter.] So what you are saying is wait until we know the answer to that problem. Their answer is increase NO_x, even while we don't know anything about acid rain. I don't think you think that is the answer.

Excuse me, Dr. Oppenheimer.

Dr. **Mohnen**. Senator Mitchell, you always address me but you don't give me a chance to respond.

Senator **Mitchell**. You have had plenty to say today, believe me. I will sit here as long as you want to talk. I said that earlier, and I will.

Let me let Dr. Oppenheimer finish.

Dr. **Oppenheimer**. The effect of the NO_x on the sulfur transformation is a complex one and is not fully understood at this point. But I just would like to point out that the same people who produced the JASON report on sulfur emissions also commented in the JASON report and in another report on atmospheric pollution that the appropriate strategy would be for the reduction of both SO_x and NO_x and that the NO_x interference or effect on the SO_2 photochemistry is not going to be one where we reduce NO_x emissions and significantly increase wet sulfate formation as a result. I know that has been bandied about lately. It seems regionally that is highly unlikely to occur, although it may occur in a few isolated instances. There is a strong disagreement between myself and Volker on this. But I see the present situation as follows: If we reduce sulfur dioxide emissions, we are going to get it back in reduced deposition. In addition, the Midwest has their deposition problems, too. We just heard West Virginia has a very nasty acidification problem now.

No matter what the range of transport is, no matter what the efficiency of transformation is, those States in the Ohio basin and Midwest region have their own deposition problems. It would be nice to help them out with some sulfur emissions reductions.

Senator **Mitchell**. Let me ask Dr. Shannon a question. I will get back to you, Dr. Mohnen.

Dr. Shannon, you have heard a lot of talk about modeling here, some of it critical. Let me ask you, has your modeling calculated the effect of enactment of my bill on wet and dry deposition of acid?

Dr. **Shannon**. Yes; I have modeled with emissions being those that were supplied from analysis of your bill by the Office of Technology Assessment.

Senator **Mitchell**. Have you compared the results that your model predicts with actual observations in the real world?

Dr. **Shannon**. I have compared results of the model's predictions of wet deposition of sulfur with observations. I cannot make comparisons for dry deposition, since it is not yet monitored.

Senator **Mitchell**. Are you satisfied that your model is a reasonable predictor of reductions in deposition that will occur if there are reductions in emissions?

Dr. SHANNON. I feel fairly confident about the model when exercised for long-time periods and over a large spatial scale.

Senator MITCHELL. Would you tell me, please, what results you predict in reductions in deposition if there is a 10-million-ton reduction in emissions within the region set forth in the bill?

Dr. SHANNON. The largest reductions in deposition take place where the largest reductions in emissions take place, so that the largest decreases in total sulfur deposition occur in the Midwest, on a percentage basis, and in some of the Southern States. On a percentage basis, the deposition reductions in the Northeast associated with Easten United States emission reductions—I was not treating Canadian sources in this particular simulation—typically were about 30 to 40 percent total reduction—some places larger, some places a little smaller. The overall reduction in deposition in the Northeast was somewhat smaller than the overall reduction in Eastern United States emissions overall. But the figures were comparable, the same order of magnitude, less than a factor of two difference.

Senator MITCHELL. Thank you, Dr. Shannon.

Dr. Mohnen, let me get back to you so you can answer the previous question. But let me raise another question that has come up. You mentioned your monitoring at Whiteface Mountain and at Champaign, Ill. As I understand what you base your conclusion on, it is that the quantity of sulfate—that is, of wet deposition of acid—in rain that came from the Midwest sector was roughly comparable to that which came from other sectors. Is that a fair summary?

Dr. MOHNEN. For the sake of completeness, I repeat two-thirds of the rain, roughly, comes from the sector that I classified Midwest and roughly two-thirds of the sulfate wet deposition came from that sector. One-fourth, roughly, came from the Canadian sector and one-fourth of the sulfate came from that sector.

As Dr. Gould pointed out, there is another sector that I personally disqualified after talking to many of my colleagues, simply because when we talk about air from the Northeast sector or from the East, this is mostly a Northeastern snowstorm, and you know what that is. So obviously you wouldn't want to compare material that was deposited by a Northeast snowstorm with something that is deposited by the more typical precipitation patterns that come Northwest, Southwest.

Senator MITCHELL. But what I am getting at, and I want to make sure I understand this, is what you are saying is that the rate of acid deposition is roughly comparable and the quantity of deposition therefore was dictated by the amount of rain that fell from a given sector.

Dr. MOHNEN. On an annualized basis, yes.

Senator MITCHELL. So there is more rain coming from the Midwest sector; therefore, there is more acid coming from the Midwest sector.

Dr. MOHNEN. This is also correct.

Senator MITCHELL. So there are two variables in there. One is the quantity of rain and one is the quantity of acid.

Dr. MOHNEN. Right.

Senator MITCHELL. Now we can't do anything about the rain, can we.

Dr. MOHNEN. Totally correct.

Senator MITCHELL. We can do something about the quantity of acid.

Dr. MOHNEN. That is also correct.

Senator MITCHELL. Since two-thirds of the total quantity of deposition measured at Whiteface came from the Midwest, is it not a fair assumption that reduction of Midwestern emissions would produce some reduction of deposition?

Dr. MOHNEN. You come right back at the most crucial question of the source-receptor relationship. What you just said is precisely what I said, and it is precisely why I did all the work at Whiteface Mountain. When I then looked at it, I found out that upwind of Whiteface Mountain we have regions that exhibit considerable differences in sulfur emissions, nitrogen emissions, and sulfur to nitrogen ratios.

Now, I could only go back with the atmospheric trajectory analysis section for 2 days—not that I didn't have the computer capability to trace back airmasses beyond 2 days but simply because every researcher in meteorology warned me not to go further back in time and space than 2 days.

Under those circumstances, my conclusions were as follows. With the existing trajectory analysis technique, with our existing knowledge of meteorology, and with the precision with which we can measure acid rain, which is quite high, I cannot differentiate what is Midwest on an annual basis and what is Canadian. It is to me as if the emission sources that lie upwind play no dominant role. Their ratio in sulfur to nitrogen is about 3 to 1 for the U.S. sector and 19 to 1 for the Canadian sector, however it doesn't matter; when the rain comes down, it is always 2 to 1.

Now, obviously, this is a first step analysis that just tells us the red flag goes up. Something is not as simple as you and I believe, or as you still believe. I do no longer believe in a linear relationship between upwind emission changes and downwind depostion changes.

Now, it also led me to looking up the reactions. We then studied or initiated a field study called acid precipitation experiment together with the National Center for Atmospheric Research. In that experiment we established that in the Northeast it must be the sulfur dioxide becomes entrained in clouds, which then subsequently is oxidized inside the cloud and reaches with rain or precipitation. Whatever goes on inside that cloud droplet, that is where the origin of nonlinearity lies. So it is not the amount of SO_2 but somehow the ability of that minute cloud droplet to process sulfur dioxide which makes the transformation suddenly nonlinear.

Based on that, I have come to the opinion that a 50 percent reduction might not yield in the Adirondacks a 50 percent reduction in the sulfate rain. In the Southwest, far away, where SO_2 is different and where the air pollution mixes different, the situation might be totally different. In Europe it might be different. This is why all of my testimony says "might." See, I am as uncertain and as cautious as I possibly can be as a scientist.

Senator MITCHELL. Thank you, Dr. Mohnen.

Dr. Gould?

Dr. GOULD. I just want to remind Dr. Mohnen that three times more precipitation comes to the Adirondacks from the Midwest than from all of New England and, in addition, that precipitation is four times more polluted in sulfate than precipitation from all of New England. Therefore, a total of 12 times more sulfate is brought to the Adirondacks by airmasses from the Midwest sector than from all of New England and parts of eastern Canada. Dr. Mohnen has focused only on--what Dr. Mohnen has done is he said, "Look, a lot of sulfate pollution is coming from the Midwest. A lot of it is coming from that sector in Canada that contains Sudbury." He is saying, "Well, there is a lot of sulfate in precipitation and, therefore, it doesn't matter where you look." That is not true. If you look at all of the data which I have presented in the statement before the committee, and the summaries of which you have, you see that in fact there is a great difference in the concentration and the total amount of sulfur that is deposited depending on where you look.

Senator MITCHELL. Let me ask you all, because the hour is late and you have all been very gracious to sit here, especially those of you who haven't said too much, would you like to say something in conclusion? I will go right down the line and see if anybody has a brief summary statement they want to make. Please don't repeat everything you said at the beginning or during the question and answer period. But if you would like to make a closing comment, go ahead. Then I have a few closing comments of my own.

Dr. Barrie?

Dr. BARRIE. Yes, I have two comments to make. One is on the question of dry deposition is contribution to the total acidity in the Northeast which has been bantied about. Two opinions were expressed, one by Dr. Mohnen, that dry deposition is insignificant compared to the total in the Northeast, and my own opinion, which I feel is well-founded in the experiences of the European studies as well as in our measurements that we have been making of air concentrations since early 1979 along the border, that dry deposition is a significant contributor to the total in the Midwest as well as in the New England States and cannot be left out of any discussion of the emissions deposition relationship.

On the question of nonlinearity, Dr. Mohnen and I really come to the same conclusion, although we don't agree on why we come to the same conclusion. I agree that there is a possibility of nonlinearity, but for every mechanism which Dr. Mohnen can give me in support of no reduction in deposition for a reduction in emissions, I can give him several that would counteract that effect. This is why I think that Dr. Oppenheimer's conclusion, that things come out roughly linear, 50 percent gives you 40 percent, is a valid conclusion.

Senator MITCHELL. Thank you, Dr. Barrie.

Dr. Demerjian, I did want to ask you a question before you close, and I don't mean to——

Dr. DEMERJIAN. I was wondering about that.

Senator MITCHELL. I don't mean to direct this at you personally, but this has been to me a very instructive and informative session. I respect the views of everyone here, even those with whom I disagree, because I think they are well-meaning and well-founded. I think it is important for Congress to get the best scientific information. I think that is also true of the executive branch.

I want to say that I am deeply distressed by a report which was just handed to me which indicates that the Reagan administration has refused a National Academy of Sciences request to conduct a scientific review of United States-Canadian studies on acid rain and instead has assigned a White House panel to carry out the study. Sources within the Academy and the Environmental Protection Agency said the White House refused to permit the Academy to perform the peer review study because the Academy has previously issued a report calling for additional pollution controls to deal with the acid rain phenomenon.

I assume you are not personally involved in that decision. I hope you are not anyway.

Dr. **Demerjian**. No, I am not. I contributed to many of those reports, as a matter of fact.

Senator **Mitchell**. I beg your pardon?

Dr. **Demerjian**. I have contributed to a substantial number of those United States-Canadian MOI reports.

Senator **Mitchell**. We here in the Congress, we here in this committee, have opened up to the views of a wide range of scientists, some with very strongly held views to the contrary, in the belief that the free and open clash of ideas and debate is the best way to reach the truth and the best answer to the problem. Yet the Reagan administration has adopted precisely the opposite tactic in denying the National Academy of Sciences, an independent scientific agency, perhaps the most prestigious scientific agency in this Nation, the opportunity to conduct a peer review of those studies and instead is going to select its own panel to do so. In the name of objectivity, bias is being inserted into the process. I think it is a very distressing thing. But you only served as an appropriate vehicle to make that statement to, Dr. Demerjian. I didn't mean to associate you with it.

I would be glad to receive any final comments you have.

Dr. **Demerjian**. Senator Mitchell, I have a couple of comments. One is that I hope that you do not feel that any of us who make statements about our personal feelings about a state of the science or the uncertainty of the science necessarily are proponents or opponents to any mitigating strategies to environmental problems. I personally have been with the agency for 8 years. There have been three administrations. I have never felt that at any point I couldn't say what I felt about particular problems.

In the case of the issue that I raised here, it is again an issue associated with what is the most effective way for getting the results that the public at large would like to see.

My concern is that I feel that many of the people that have spoken to the nonlinear systems here are just not familiar with much of the work that has gone on in our agency in terms of addressing problems; for example, hydrocarbon NO_x in relation to oxidant production in this country, and the fact that nonlinear models on urban scales have been developed to institute standards we have in the Clean Air Act. There is a great deal we understand about the nonlinear processes. Hydrocarbon, NO_x, oxidation and the production of peroxide in urban areas. Much of that work can be expanded to this problem.

My concern is that there are decisions being made that aren't taking advantage of much of that knowledge, incorporating it into this process, so that we might not be looking at the most effective way of mitigating acid deposition.

That is all I want to present is the fact that there are significant scientific results that are based on other programs that this agency and that the Clean Air Act has mandated in terms of problems we need to study, and many of them do address nonlinear processes, and that several of the key pathways that have been identified by Dr. Oppenheimer and which I have personally been involved with in terms of the science—he mentioned Jack Calvert's work. I was one of his students and did much of the SO_2 chemistry involved in that activity. I have also done a lot of work on photochemical mechanisms on the atmosphere. They all point to the direction that the atmosphere is very nonlinear and it is sensitive to the hydrocarbon NO_x distribution across the country and the potential reactivity of those organic compounds and the distribution of the NO_x that we find.

All I am saying is that I hope that you recognize the fact that there are those uncertainties and they potentially could dampen many of the hopes of your strategy in terms of reducing acid precipitation.

Senator MITCHELL. Thank you, Doctor. I assure you that I did not intend to question in any way your own personal commitment, nor indeed that of Dr. Mohnen or Dr. Rahn, with whom I have disagreed here. I think they are all acting out of the very highest of motives and intentions. We just disagree on that.

I do want to ask you one question because your statement aroused my interest. One of the things that has troubled me about this whole argument that we have to study it more has been the adamant refusal of everybody who has made that argument to tell us when we might have an answer. I questioned your superiors, Mrs. Gorsuch and I don't know if Miss Bennett is your superior or not, but she is involved in it down there, repeatedly. I questioned many of the people I met privately when posing my bill as to when that might occur. All I ever get is well, we don't know; 5 years, maybe 10 years. But then the studies may raise more questions.

In other words, do you have a present estimate of when we would have enough information upon which to base the kind of judgment that you would like to see made?

Dr. DEMERJIAN. Yes; I would try to answer that for you. It is something we are obviously hassling with right now or wrestling with in the national acid precipitation assessment plan. We are preparing 5-year strategies for that research program.

Of course, one of the products we would like to see of that program is the answer to the question you are very interested in for resolving policy issues. My personal feeling is that there will always be uncertainty in models. It is going to be up to the decisionmakers to accept that within the process in which they derive policy.

My problem with that uncertainty right now is that I personally feel there is a major flaw in the current techniques we have available. I think that flaw can be remedied probably in a 3-year timeframe. That is, I believe it is possible to incorporate sufficient nonlinear processes within existing modeling frameworks so that that flaw can be eliminated. There will still be uncertainty. We will still have to come to you and say:

> Senator Mitchell, this is the uncertainty we expect based on these strategies. When you go through this exercise, you will have to appreciate that this is the best we can tell you.

Five years from now. The hope is we could squeeze it down even more. There will be a point where it won't be worth anyone's while to squeeze it down any more. There is inherent inaccuracy just because of the dynamics of the atmosphere. But certainly within what we think is possible within a 5-year timeframe there should be significant understanding of those uncertainties within those models so there won't be the kinds of questions I am raising to you today in terms of what the most effective way is to get from "A" to "B."

Senator MITCHELL. I don't at all question your good faith.

Let me just say, there is not the slightest doubt in your mind, is there, though, that 3 years or 5 years from now those who are opposed to this bill because they would be affected by it will still be citing some evidence, Dr. Mohnen's studies, Dr. Rahn's studies, someone else's, for inaction. My God, we could get a panel of scientists up here today and we could get half of them to say that smoking has nothing to do with cancer.

Dr. DEMERJIAN. I agree with your point. You can always find critics. I agree with that. What I am saying is that, from again a scientific credibility point of view, one of the things you try to assure yourself is that you have incorporated your best state of the art understanding of the physics and the chemistry of the process in which you are trying to understand the source-receptor relationship.

In my opinion, the present generation models do not have that sophistication at this point. I am saying we know many things about the nonlinear chemistry and they are not reflected in the models as of today. I am saying that reflection could be done in this 3-year timeframe within what is planned in the agency's program under the national acid precipitation assessment plan.

Senator MITCHELL. I would merely point out also that under my bill, it would be approximately 3 years before any specific action were required to be taken, and that should further studies provide the dramatic negative information which you suggest, and this proved to be wholly unwise, why then of course the Congress could act accordingly.

On the other hand, however, should it turn out that the premise upon which this bill is based is a valid one and we not act now, then we will have lost 3 years and we will be further down the road with increasing and accelerating damage to all of the bodies of water. It seems to me your statement is one of the best arguments I have heard yet for my bill. I thank you for it.

Dr. Gould?

Dr. GOULD. Senator Mitchell, in my judgment the scientific evidence currently available supports all of your perceptive comments, and I don't wish to add to them.

Senator MITCHELL. Thank you, Dr. Gould.

Mr. Hicks?

Mr. HICKS. A couple of small points come to mind. I thank you for the opportunity, Senator.

Regarding dry deposition, we have heard a lot about sulfate and nitrate. No one has emphasized that in fact ammonium is a material that has an acidic effect upon receptors. It is difficult to relate wet deposition of some species with dry deposition of that same species and then to extend the comparison to make statements about wet versus dry deposition of acidic compounds overall. There are many different complicating factors that should be considered.

The second point concerns chemical nonlinearities. We have heard enough today about nonlinearity to last me for the week at least. However, early on in this game I remember that a number of us sat down and discussed this same issue and decided that what went into a cloud would probably come out. That was our approach to nonlinearity.

Regarding the subject of deposition to specific receptors——

Senator MITCHELL. That has the disadvantage of being too closely related to common sense, Mr. Hicks, to be widely accepted, I think.

Mr. HICKS. A compliment, I think.

Regarding deposition to specific receptors, we hear a lot of talk about impacts upon forests, upon lakes, upon different surfaces. All of these have different uptake characteristics and are located in different areas. For example, forests are usually in complex terrain. If we are indeed concerned about the dry deposition impact of acidic materials to receptors like forests, then we must learn more about the complex terrain. It is difficult to disassociate the two problems.

Thank you.

Senator MITCHELL. Thank you, Mr. Hicks.

Dr. Holmes?

Dr. HOLMES. I certainly agree with most of the members of the panel here that it would be a good idea to do some more research. But I don't think it is realistic to believe that at any time in the future, no matter how much more work we do, we are going to have full and complete knowledge of the acid rain problem. On the contrary, I think more research is likely to produce more things for us scientists to argue about. Your analogy with the 1970 Clean Air Act is entirely appropriate. I think the assumption then was that the hydrocarbon NO_x ozone system was somehow, more or less, linear; that a given amount of hydrocarbon control would give a corresponding amount of oxidant control, and we proceeded on that basis. Well, now after 10 years or more of this sort of modeling that Ken just talked about we know that the system is sometimes nonlinear, but we know that, for a large region of that hydrocarbon-NO_x plane, it is fairly close to being linear and that the 1970 assumptions, although they were based on incomplete evidence, were pretty much correct at least for most of the atmospheres we find in urban areas of this country.

As for the question of transport or nontransport, I really can't speak knowledgeably to that. But from what I understand of Dr. Rahn's data, I think his data base is so sparse, the analysis is so fragmentary, that it certainly does not raise a red flag in my mind.

On the other hand, I am aware of a number of other studies—some of them are cited in my testimony; others have been talked about here today—where equally reputable scientists have concluded that there is a very frequent, regular pattern of transport of acid aerosol and acid precipitation to the Northeastern part of the country from the Midwest. It is not a question of trying to analyze it day-by-day as to exactly what happens or even week-by-week. But the long-term, seasonal, annual averages the long haul is what counts.

It is clear to me that controls in urban industrialized areas, to the south and west, are going to substantially reduce the severity of the problem in the Northeast. We can quibble about just exactly how much and on just which days or which months. But I think the general approach you have proposed is the proper one.

Senator MITCHELL. Thank you very much, Dr. Holmes.

Dr. Mohnen?

Dr. MOHNEN. Senator Mitchell, I want to take this opportunity to thank you for bringing me down here. I have submitted to you an extensive statement, both my oral statement and my written statement. Should you have any questions, I will be most happy to answer you or your staff. Otherwise, thank you again.

Senator MITCHELL. Thank you, Dr. Mohnen.

Dr. Rahn?

Dr. RAHN. I would just like to predict that after a few years have gone by a lot of these difficulties a lot of us are having with the concepts about manganese and vanadium and in a more general way about elements will have disappeared. We are experiencing I believe the birth of an additional technique which can be applied with great vigor and with great fruitfulness to many atmospheric problems, one of which is acid precipitation, transferred with acidic matter around the Northeast. It is going through some childbirth pains, I suspect. There is a lot of uncertainty yet. We have seen maybe 1 percent, one-tenth of 1 percent of what is possible with this sort of approach, and it will achieve its greatest fruitfulness when it is combined with the other approaches available today, such as meteorological analysis and modeling and so forth that is never intended to stand on its own.

I for one intend to continue working with all the vigor that I can apply to this in this field and hope that it will resolve some of these problems we have.

Senator MITCHELL. Thank you, Dr. Rahn.

Dr. Shannon?

Dr. SHANNON. I feel that whoever came up with the term acid rain some years ago did both a service and a disservice because it is a very catchy phrase. It definitely gets the issue in the public eye. But I think it will cause us to, as a public, underestimate the effects and importance of dry deposition, no matter how much we bring it up in panel discussions.

We would like to be able to reduce emissions in such a way that the cost of reduction is minimized and the benefit is maximized. To do that we would like to reduce our uncertainty. And we have talked about things here that address uncertainty just in the atmospheric transport and deposition, chemical transformations, et cetera, aspects. Well, there is also uncertainty, great uncertainty, among the people involved in ecological effects modeling. Now, that uncertainty is convoluted in some involved manner with our uncertainty. Then further along the line there is uncertainty involved for the people who do assessments. Some of that uncertainty can never be eliminated because some of the damages that we associate with acid rain have to do with damage to lakes and fish populations.

Now, if you are assessing the cost of an action, then you determine that these plants will have to take this action and it costs $400 million to do this retrofit, et cetera. It puts these miners out of work. You have hard numbers, hard dollars. They may print those figures. They may print out five figures. It doesn't necessarily mean they have five figure accuracy. They translate generally into a dollar figure.

But when we get into the effects assessment end, how much is the fish population in some lakes in the Adirondacks or in Maine worth? There is a great deal of subjectivity in that today and there will be subjectivity in that a hundred years from now,

Visibility, which is a related issue, that we haven't touched upon today, is similar. It is very difficult to quantity in a rigid dollar and cents fashion to enable one to come up with an optimal action in terms of cost and benefit. We will always be faced with that problem.

So the point of view that we have to delay action until all of this uncertainty is eliminated is, I feel, simply a delaying action. There is a lot about the problem that we don't know. But there is a lot we do know and I think that is underemphasized.

Senator MITCHELL. Thank you, Dr. Shannon.

Dr. Oppenheimer?

Dr. OPPENHEIMER. We can sit and wring our hands and throw up smokescreens and wonder about the value of the scientific research being produced or that which has been published for years. We can go on with that process for many years if we like and not do anything about this problem. But I think that a fair-minded view of the state of scientific knowledge today tells us if we reduce sulfur emissions, that we will reap substantial benefits in terms of reduced total acid deposition. That is exactly what we are after. At least that is what I am interested in.

My view is that scientific research should progress. But the progress in scientific research cannot stand in the way of the political decision to take action on this problem now.

Of all the public policy issues I have seen, it seems to me this one is clearer than most with regard to the need, the desirability and the effectiveness of proposed action. We should get on with the business of taking that action, which is primarily the reduction of sulfur dioxide emissions.

Senator MITCHELL. Thank you.

I would like to make just a few closing comments. First, this has been a most useful proceeding. I personally have learned a great deal from it, as is so often the case. If we have open minds, we learn from those who don't agree with us. I have learned a great deal. I am sure the other members of the committee will benefit greatly from your contribution here today. Many of them had other pressing commitments, but you can be certain that they are all represented by staff and that your comments will be reviewed by them as they make a decision.

I do want to point out the focus of this hearing was on an important but narrow part of the problem, deliberately so. No effort was made to deal in any detailed way with the effects of acid rain or acid deposition and other important parts of the problem. That has been covered in other hearings.

At the risk of repetition, I want to make clear that we dealt here with the very narrow part of the problem, one in which there is some uncertainty and some clash of views among distinguished scientists, as we have seen here today. But Dr. Shannon made a point I think that has to be emphasized. Enactment of control legislation will not create a new cost for our society because a cost is already being exacted on our society. It will merely transfer the cost from those who are now receiving the disadvantages and not getting the benefits to those who are getting the benefits without suffering the disadvantages. It is more difficult to assess cost in an environmental sense and in a damage sense than in a remedial sense. We can find out right down to the penny what it costs to install a scrubber or what it costs to wash coke or what it costs to engage in other control activities. The value of trout surviving in a small pond in northern Maine is not so easy to assess. The value of the loss of the Atlantic salmon from nine rivers in Nova Scotia is not so easy to assess. But if our society stands for anything now, it stands for a commitment by the people of this country, expressed over and over again, in clear, unmistakable and overwhelming terms, to bear the burden that is necessary to have a clean, healthy environment. Clean air and clean water are not just empty slogans in this country. They are meaningful to the overwhelming majority of Americans.

I submit that the people of this country have said over and over again they want clean air. They want clean water. And they are prepared to pay for it.

I don't suggest that we are a nation of unlimited resources. You are quite correct, Dr. Mohnen, when you say that the news carries nightly reports of our difficulty in making allocations of our resources. But in a democratic society, the people's view must be given great weight. In this society, the people's view is unmistakable. They want clean air. They want clean water.

I want to emphasize one other point. That is this bill does not by its terms discriminate against any area or any State. It is designed to stop an activity that few dispute is seriously harmful. Necessarily, the burden must fall primarily upon those who are engaging in the activity. But this does not exempt any State from sharing in the burden of cleanup. It applies to every one of the 31 States in the Eastern region, including my own State of Maine, which will have to make reductions as will every other State.

It gives maximum flexibility to the States and the industries to achieve the reductions in the most efficient and cost-effective manner.

In some of your statements and your speeches, Dr. Mohnen, you have talked about advanced coal washing. You have talked about a number of other things. All of them are contemplated by this legislation. No single method of reduction is mandated. It is left to the affected industries and the States in developing their implementation plans to come up with the method of reduction that is most efficient, most effective, and that will cost society the least.

Although there have been disagreements expressed here, and I have great respect for the views of those who have expressed opposition to my legislation, I will say in conclusion that this hearing greatly strengthens my conviction that legislation is needed and it is needed now to address what is a most serious national environmental problem, not just affecting the people of New England but affecting all of the people of this country, because the waters, the resources of New England don't just belong to the people of New England. We don't protect the Grand Canyon just for the people of Arizona. We don't preserve the redwood forest just for the people of California. And the Grand Teton Mountains don't just belong to the people of Wyoming. There are certain resources that are natural and national in scope, and they belong to all of the people, and they deserve protection. My bill will protect them.

I thank all of you very much for coming here today.

[Whereupon, at 2:00 p.m., the committee was recessed, to reconvene at 10:00 a.m. on Thursday, May 27, 1982.]

[Statements submitted for the record follow:]

Statement by Dr. L.A. Barrie, Atmospheric Chemist, Research Directorate, Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ontario, Ontario, Canada M3H 5T4

Prepared for a technical enquiry on Acid Rain hosted by the United States Senate Committee for Environment and Public Works, May 25, 1982

At the outset I wish to emphasize that the opinions expressed in this testimony are my own and not necessarily those of the Canadian government.

Since the theme of this enquiry is 'the level of uncertainty in our understanding of the long-range transport of pollutants and the associated acid rain problem', I will attempt to separate those aspects of the phenomena that are quantitatively well understood from those with a higher degree of uncertainty. To do this, I will discuss the issues within the context of the atmospheric cycle of acidic pollutants. The oxides of sulphur and nitrogen are the main contributors to acidic deposition.

AT THE SOURCE

In this discussion, it is important to understand the difference between primary and secondary particulate matter. Primary particles are those released to the atmosphere at the source. Secondary particles are formed in the atmosphere downwind of the source from the chemical conversion of gases.

It is well known that at those sources from which most of the sulfur in eastern North America is released more than 95% is in the form of sulphur dioxide; the remaining 5% consists of primary sulphuric acid particles containing traces of metals including manganese and vanadium. There are other sources of primary particulate matter, that contain sulphuric acid as well as trace elements including manganese and vanadium. It is hypothesized by Dr. Rahn that the ratio of manganese to vanadium in primary particles can be used as tracers of substances acidifying rain. This might be true if most of the acidity of rain came from primary particles and if sulfuric acid particles and manganese or vanadium-bearing particles were released by the same sources. However, it is known that this is not the case. Most of the acidity of rain originates from gaseous oxides of sulphur and nitrogen. Furthermore, the bulk of the manganese and vanadium particles are released to the atmosphere at lower levels than sulphur particles and gases. In other words, trace metals finger-print only a small fraction of the total acidity (only a fraction of the primary sulphate emissions and none of the gaseous emissions) and therefore cannot be used to identify the source. Thus the manganese-vanadium ratio technique is of no use in identifying the source of acidity.

The fate of the acidic oxides of sulphur and nitrogen once they are released to the atmosphere has been studied on a wide range of spatial scales. From mass budget studies around elevated, stationary point sources undertaken by myself and others, it is well established that on the average more than 95% of the acidic material is transported beyond 100 km of the origin. During precipitation more pollutant will be removed within 100 km than otherwise but, since precipitation occurs infrequently (2.5- 5% of the time in eastern North America), most of the emissions escape beyond 100 km.

BEYOND THE SOURCE

As pollutants are transported, they are dispersed in the horizontal and the vertical. They are also chemically transformed and removed.

Oxidation and Wet Removal

While enroute between source and receptor, the acidic precursor gases can be oxidized to acids in clear air and in clouds. In areas of non-raining clouds, the pollutant mix is circulated through a cloudy environment and then, in a transformed state, back into clear air. In a raining cloud, a portion of the transformed pollutant mix is removed. In general, in-cloud sulphates are scavenged more efficiently than sulphur dioxide. Consequently, the degree of in-cloud conversion of sulphur dioxide to sulphate is an important factor in the acidification of rain. There is a growing body of evidence indicating that, of the acidity attributable to sulphur compounds, at least two thirds originates from in-cloud conversion of sulphur dioxide to sulphuric acid, the rest from sulphate particles originating from outside the cloud*. On the basis of laboratory experiments, it is known that a number of substances promote the in-cloud oxidation of sulphur dioxide. These include hydrogen peroxide, ozone, manganese, iron and possibly nitrogen dioxide itself. Hydrogen peroxides originate from chemical reactions of man-made nitrogen oxides and hydrocarbons; ozone and manganese come from both man-made and natural sources, and iron from soil. At this time, the ability of each of these substances to oxidize sulphur dioxide has been studied individually but not in combination. Furthermore, little is known about reaction rates at super-cooled temperatures that often prevail in cloud water.

Because of the complexity of in-cloud processes such as sulphur dioxide conversion, empirical relationships are used to represent them in mathematical simulations of the acid rain phenomena. In my opinion, a useful assessment of the contribution to acidity in one region of the northeast caused by emissions in other regions can be made using existing models that employ empirical techniques if they are used in combination with actual meteorological and precipitation chemistry measurements.

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*those originating from primary sulphate and clear air conversion of sulphur dioxide

Dry Removal

Before discussing present model estimates of source contributions to acidity, I would like to spend a moment stressing the importance of a dry deposition, a frequently under-rated component of acidic deposition. Acidic pollutants are not only removed by wet deposition processes (rain and snow) but also by direct interaction with the earth's surface. This is called dry deposition. The fraction of total deposition that is dry deposited depends on the amount of annual rainfall as well as one's distance from the source. It decreases as one proceeds away from major source regions. Using deposition velocities determined in research studies that have been conducted over the last decade, dry deposition can be estimated within a factor of two accuracy from ambient air concentrations that are measured routinely, Available evidence (measurements in Europe and Canada) indicate that dry deposition processes contribute about 50-70% of the total sulphur deposited in or near major source regions such as Ohio, Pennsylvania and Indiana and, about 20-30% downwind in New England. In the discussions that follow, total deposition will be emphasized.

CONTRIBUTORS TO NEW ENGLAND DEPOSITION

Atmospheric model estimates of the contribution of emissions in various states or provinces to total deposition on eastern North America are being conducted under the auspices of the United States/Canada Memorandum of Intent negotiations. Eight independent modelling groups are involved (three Canadian and five American). Dr. Shannon, a member of the panel at this enquiry, represents one of the American groups.

Two important features of the long-range transport problem that all models agree on are:

1. total annual sulphur deposition in any New England state is made up of many small contributions from other states or provinces.
2. total annual deposition in the Adirondacks and Northern New England is apportioned to source region as follows: 35-50% originates from the mid-west, Pennsylvania and New York each contributing about the same amount 10-15% and 20-40% comes from Canada.

Thus, only by reducing major sulphur emissions in all states and provinces of eastern North America can we significantly alleviate the problem of acidic deposition.

EMISSIONS CONTROL

We ask ourselves whether a roll-back of emissions will indeed achieve a decrease in total acid deposition. Dr. Mohnen has argued that atmospheric chemistry and removal processes are such that in the airshed of the northeast a decrease in sulphur dioxide emissions will bring about a much smaller percentage decrease in wet deposition. That is, rather than a linear relationship between emissions and wet deposition there is a non-linear one. But when emissions change, one has to also consider what happens to the other major component of total deposition, namely, dry deposition. If a decrease in emissions were not accompanied by decreased wet deposition, as Dr. Mohnen postulates, the concentration of sulphur dioxide in the air and the associated dry deposition would decrease even more than in the linear case. In other words, if a reduction of emissions does not manifest itself in a reduction of rain acidity, (which is highly unlikely) it will manifest itself in a reduction of dry deposition.

NITROGEN OXIDES

In any debate of the acidic deposition problem, it is important to consider the role that nitrogen oxides play. On an annual basis, 70-80% of the acidity in northeastern precipitation comes from oxides of sulphur and the rest from nitrates. Freshwater lake biologists point out that nitrate-related acidity is essentially neutralized when the ion is digested by aquatic biota, and that, consequently, sulphates are the main source of lake acidification. However, if nitrate acidity, were to have environmental effects, elimination of sulphur emissions would not totally solve the problem of acid deposition. It is also worth mentioning that nitrogen oxides are a major contributor to the photochemical production of ozone and other atmospheric oxidants that are known to cause damage to forests and agricultural crops. Consequently, consideration should be given to reducing nitrogen oxide emissions in parallel with those of sulphur dioxide.

ON THE DETECTION OF THE EFFECT OF A REDUCTION IN EMISSIONS

Because of the natural variability of the weather, the effect of an abrupt change in emissions may be difficult to document with a high degree of certainty unless the new level of emissions is sufficiently different from the old level and is maintained long enough for precipitation chemistry measurements to be made for a number of years. A 40% emission reduction in the eastern United States will have to be sustained for at least five years before an accurate determination of the corresponding reduction in deposition can be made. In view of this, it is not surprising that researchers at Hubbard Brook, New Hampshire (Likens, Cornell University) have found no significant change in levels of acidity in precipitation since 1964. Emissions of pollutants in all regions upwind of New Hampshire oscillated in an unsustained fashion. Each region's emission trends were different. In EPA region V, a major source region (Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin), sulphur emissions increased 16% between 1960 and 1965 and gradually decreased by 18% from 1965 to 1978. In the same region, nitrogen oxide emissions increased by 25% between 1960 and 1978. In the east coast states (EPA regions I, II, III), emissions of both sulphur and nitrogen oxides decreased between 1960 and 1978. In the southeast (EPA region IV) they increased. Thus, there was no consistent, sustained change in emissions of acidic substances upwind of Hubbard Brook that would enable one to detect a change in precipitation quality above fluctuations caused by meteorological variation. In other words, Hubbard Brook data cannot be used by critics of action to reduce emissions, such as Dr. Mohnen, as proof that a reduction in emissions will result in little change in acid deposition since, in fact, emission changes have not been large enough nor sustained enough for a relationship between emissions and deposition to be resolved above meteorological variability.

STATEMENT OF
DR. KENNETH L. DEMERJIAN
DIRECTOR, METEOROLOGY AND ASSESSMENT DIVISION
ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
U.S. ENVIRONMENTAL PROTECTION AGENCY
BEFORE THE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

MAY 25, 1982

Good morning, Mr. Chairman and Members of the Committee. I am Dr. Kenneth L. Demerjian, Director, Meteorology and Assessment Division, Environmental Sciences Research Laboratory of the U.S. Environmental Protection Agency. I welcome the opportunity to meet with you today to discuss the issue of atmospheric processes as relates to acid deposition. I will share with you details concerning the research activities underway at the U.S. Environmental Protection Agency which should enable us to learn more about the atmospheric processes that dominate the acid precipitation problem. I shall briefly discuss the history of our atmospheric processes research program and its current status as well as the outlook for the next few years. I shall highlight the major efforts within the atmospheric processes research program from which we expect results in the next three to five years. Finally, I shall discuss an example which is representative of the work we are undertaking in this area. This latter discussion should provide you with a greater sense of the nature and magnitude of the present uncertainties that prevail in our ability to understand and cope with the problem.

Introduction and History of EPA's Atmospheric Processes Research Program

EPA has been involved in research relating to atmospheric processes in acid deposition for some four years. Our research program in this area effectively began in 1979, following the transfer of research responsibilities from other atmospheric processes research areas into the National Acid Precipitation Assessment Program. Recently, funding for the program has increased from about $3 million in Fiscal Year 1981 to over $4 million in Fiscal Year 1983.

To date, the program has supported large amounts of field work on the chemistry of atmospheric formation of sulfates and nitrates, on vertical and horizontal transport mechanisms, and on wet scavenging and dry removal of acidic compounds.

Despite the fact that this research has revealed some important findings, we need to understand a great deal more before the results of this research can serve as the basis for regulatory decisions. A number of key areas of the research have demonstrated the complexity of the scientific issues related to acid deposition. Consequently, the results of our research to date have included both answers and additional questions.

Indicative of the difficulties experienced in this work and the continuing need for further work is the critical area of modeling to relate source emissions of SO_x and NO_x to ultimate deposition. To date, a number of trajectory-type models have been produced. Right now, to get an operable model requires such simplification in areas as linear chemistry and averaged meteorological conditions that the reliability of these models is in question. These models cannot generally be used for source-receptor determinations until we better understand the magnitude of uncertainty introduced by these simplifications. We expect that further field work will produce data bases and relationships which will enable us to develop improved models.

Highlights of Our Scheduled Research Program

Our research program in this area is directed toward reducing such uncertainties. The major components of our atmospheric processes research program which we expect will help reduce the uncertainties in the next three to five years include the following research activities.

The Role of Atmospheric Chemistry to Define What Precursors of Acid Deposition Should Be Controlled

- Determine for different meteorological conditions whether sulfur dioxide or oxidants are the limiting component in atmospheric reactions to produce acid sulfates.
- Since the conversion of NO_2 to nitrate and the deposition of nitrates both appear to be faster than the similar processes with sulfur compounds, the relative importance of sulfur to nitrogen deposition as a function of distance from the source region will be quantified.
- Determine under what atmospheric conditions, neutralizing agents (such as windblown alkaline dust or ammonia) will affect the acidity of deposition.

Local Sources

- Conduct a field study to provide a data base for the validation of existing mesoscale models which will be used to determine under what meteorological conditions local sources dominate the acid deposition.

Source-Receptor Relationships

- Conduct a major field study to provide the first available data base on long distance (1000 km) trajectories which will be used for source-receptor model validation and trajectory forecasting.
- Develop and validate a grid-type model which incorporates the non-linear chemistry for sulfur, nitrogen and volatile organic compounds and the meteorology of horizontal and vertical transport.
- Improve one or more of the existing simpler trajectory type models by adding improved parameterization of the non-linear chemistry and transport which will be derived and validated from the more precise grid-type models.
- Quantify the inherent uncertainties in the models in terms of their ability to forecast source-receptor relationships for control strategy evaluation purposes.

The Spatial and Temporal Variations in Acidic Deposition

- Provide annual reports on the spatial and temporal variability of wet deposition from monitoring networks.
- Upgrade the methodologies for monitoring wet deposition by providing instrumentation for real-time measurement of pH and selected anions and cations.
- Install a network for monitoring dry deposition using the best available methodology which will exist in approximately three to five years.

Example of Work to Improve Trajectory-Type Models

I would now like to discuss an example of our work to improve trajectory-type models--the CAPTEX study, that is the Cross Appalachian Tracer Experiment study.

EPA, in a cooperative effort with the Department of Energy (DOE) and the National Oceanographic Atmospheric Administration (NOAA), has been working to develop long range tracers which can be used to track trajectories for up to 1000 kilometers.

This information is essential in order that we might assemble a data base which can be used to develop better methods for prescribing trajectories in models and to validate existing and future models. A data base adequate for these purposes does not exist today. It is suspected, under some conditions, that current methods for prescribing trajectories are incorrect. Preliminary work to date indicates that perfluorocarbon tracers may provide what is needed.

EPA along with DOE, NOAA and the Electric Power Research Institute (EPRI) is planning a major field study for the summer of 1983 in which trajectories will be tracked from a power plant across the Appalachian Mountains. We are also investigating the possibility of using trace metal signatures (such as manganese to vanadium ratio or lead to vanadium ratio) and isotope tagging in the field experiment.

We expect that the results of these studies will help us to develop a data base which defines

--the effect of vertical transport between the mixed layer and the transport layer on horizontal transport, and

--the appropriate wind-averaging technique to use to model trajectories in each layer.

Finally, we expect that this and other work will help us to improve and eventually validate trajectory-type models.

Summary

Mr. Chairman, this concludes my statement outlining our research program relating to the atmospheric processes of acid deposition. I would be happy to respond to your questions.

BEFORE THE

SENATE COMMITTEE ON

ENVIRONMENT AND PUBLIC WORKS

Honorable Robert T. Stafford, Chairman

STATEMENT OF ROY R. GOULD, Ph.D.

Interdisciplinary Programs in Health

Harvard School of Public Health

Boston, Massachusetts 02115

May 25, 1982

My name is Roy R. Gould. I hold a Ph.D. degree in biophysics from Harvard University. I am currently a Research Fellow at the Harvard School of Public Health and the Center for Earth and Planetary Physics at Harvard University, where for the past year and a half I have been working intensively on acid deposition.

Sulfur dioxide emissions are recognized as the chief cause of acid deposition in the Eastern United States. (National Research Council, 1981). In this Statement, I will briefly address two questions: Where does the sulfur deposited in the Northeast come from? and Will reducing sulfur emissions

significantly reduce acid deposition?

WHERE DOES THE SULFUR THAT CONTRIBUTES TO ACID DEPOSITION IN THE NORTHEAST COME FROM?

The scientific evidence currently available shows unequivocally that regions with the highest sulfur emissions, particularly the Ohio Valley, contribute the most to acid deposition in the Northeast.

From the large body of evidence that dictates the above conclusion, I will describe just one particularly important and illustrative study -- the Multistate Atmospheric Pollution Power Production Study. The measurements described below come from a monitoring station at Whiteface Mountain in the Adirondacks, a site of special interest since the Adirondacks are particularly vulnerable to acid deposition.

The monitoring station measured the sulfate content of each rainfall and snowfall in the Adirondacks during the year 1978. In addition, the direction -- or "sector" -- from which the air masses bringing each storm came was determined by a technique called "trajectory analysis." Together, these measurements allow one to determine **how much sulfate pollution comes to the Adirondacks from each sector**. These data have been presented by Wilson, Mohnen and Kadlecek (1980), and so far as I know, the data themselves have not been disputed by anyone.

The data for the Adirondacks show the following (refer to Figures 1, 2, and 3):

The level of sulfur pollution in rain and snow in the Adirondacks depends strongly on which direction the precipitation comes from. (Figure 1).

Precipitation coming from the Midwest sector contains the highest concentrations of sulfate.

Precipitation coming from the sector that includes Sudbury, Canada, also delivers high levels of sulfate.

Precipitation from the remaining sectors -- which include Eastern Canada and all of New England -- contains only about **one-quarter** as much sulfate as precipitation from the Midwest.

The regions that deliver the most polluted rain also contribute the greatest amount of rain, thus compounding the problem. (Figure 2).

The amount of sulfate that actually hits the ground depends not just on how *polluted* the rain is, but also on how *much* rain falls.

Most of the precipitation in the Adirondacks comes from the Midwest sector, and a fair amount comes from the Canadian sector as well. This is simply due to the fact that winds tend to blow from west to east.

The total sulfate delivered to the Adirondacks in precipitation depends very strongly on which direction the precipitation comes from. (Figure 3).

The total amount of sulfate that comes down -- and the acidity that it represents -- is the quantity that is harmful to the environment. The total sulfate delivered by each sector is determined from the data in Figures 1 and 2. The result is shown in Figure 3.

About 2/3 of the sulfate deposited in the Adirondacks comes from the Midwest sector.

Roughly one-quarter comes from the Sudbury sector.

The remaining sectors contribute only a few percent of the total. *New England and Eastern Canada together contribute less than 5% of the sulfate that falls on the Adirondacks.*

These results are corroborated by numerous other studies that document the transport of substantial amounts of sulfur from the Midwest region into the Northeast. (Abrams, 1981). Such studies include direct airborne measurements, satellite observations, theoretical calculations, and the use of chemical tracers similar to sulfur, such as selenium.[1] (Thurston and Spengler, 1981).

The majority of sulfur emitted by high emissions states such as Ohio must be transported out of state, to be deposited downwind.

This is easily seen by comparing the amount of sulfur that is emitted by Ohio with the amount of sulfur that falls on Ohio. The difference is a measure of how much sulfur must be transported to other states.

The amount of sulfur that falls in precipitation is about 120,000 tons annually over the entire state of Ohio. The amount of dry deposition of sulfur (as dust, gas, etc.) is typically equivalent to wet deposition (Kerr, 1981). To be conservative, assume that dry deposition is twice as great as wet deposition. Then the total sulfur that falls on Ohio is roughly 360,000 tons annually. But Ohio emits at least 1,800,000 tons of sulfur annually. *Therefore at least 80% of the sulfur emitted by Ohio must be transported out of state, to be deposited downwind.*[2]

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[1] Selenium should not be confused with manganese, whose use as a tracer for Midwestern coal (Rahn, 1981) has been shown to be invalid (e.g. Wolff, 1982).

[2] This is a crude estimate. Dry deposition of sulfur close to sources without tall stacks may be greater. On the other hand, some of the sulfur deposited comes from other states' emissions,

A similar result holds for the other Midwestern states with high emissions: most of the sulfur is transported out of state.

If it is deemed desirable to reduce sulfur deposition in the sensitive areas in New York and New England, then the results above indicate that it would be most efficient to focus control efforts on sulfur emissions in the Ohio Valley, which contribute the majority of sulfur to the Northeast.

WILL REDUCING SULFUR EMISSIONS REDUCE ACID DEPOSITION?

Reducing sulfur emissions must reduce acid deposition at all locations downwind.

All of the sulfur emitted from smokestacks falls to earth downwind, and all of that sulfur contributes acidity to the environment. Therefore, reducing sulfur emissions must reduce acid deposition downwind.

It has been known since the middle of the nineteenth century that sulfur dioxide emissions are ultimately converted to acid plus sulfate. This conversion can take place while the sulfur dioxide is still in the air, and it can also take place *after* the sulfur dioxide has returned to earth. (Smith, 1872). There are many different chemical pathways by which the sulfur dioxide can react, but they all ultimately lead to acid plus sulfate, which is the chemically stable end-product of sulfur exposed to the air.

Thus sulfur contributes acidity to the environment *regardless* of whether it first returns to earth as sulfur dioxide or as sulfate, and *regardless* of whether it returns to earth in rain, or in the dry period between rains. ("Acid rain" is thus just one of the pathways by which sulfur contributes acidity to

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not Ohio's. This latter factor will increase the fraction of sulfur transported out of state.

the environment.)

The detailed atmospheric chemistry by which sulfur dioxide is converted to acid sulfate will have a bearing on the *geographical distribution* of sulfur deposition. This is due to the fact that sulfate has a longer average "residence time" in the air than does sulfur dioxide, and thus can be blown further downwind before it falls to earth.

However, *both* sulfur dioxide and sulfate can be transported hundreds of miles downwind from their sources. Therefore reducing sulfur emissions will reduce acid deposition for long distances downwind.

Reducing sulfur emissions will substantially reduce sulfate levels downwind.

Particular attention has been focused on sulfate formed in the atmosphere, since sulfate can be transported even further downwind than sulfur dioxide, and since sulfate contributes to a number of problems such as "acid haze" and reduced visibility. The claim has been made that reducing sulfur emissions "might" not lead to a significant reduction in sulfate formation. (e.g., Mohnen, 1981). This claim is clearly refuted by the evidence:

1) Reducing sulfur emissions *has been observed* to reduce sulfate levels in the air commensurately.

Sulfur dioxide emissions in the Southwest region were reduced by approximately 85 - 90% when a strike shut down 9 of 11 copper smelters in Arizona and New Mexico during the summer of 1980. Sulfate levels in the air were observed to drop by 50 - 90% compared to the preceding summer. (Eldred et al, 1981). This was a particularly important study, because factors other than sulfur dioxide emissions -- such as weather, height of smokestacks, etc. – remained the same.

2) For the two major chemical routes by which sulfate is believed to be formed in the atmosphere, sulfate formation has been shown to be proportional to the level of sulfur dioxide in the air, provided that sufficient levels of oxidant molecules are available. (Calvert et al, 1978; Martin and Damschen, 1981).

For one of the pathways ("gas-phase oxidation"), it has been estimated that sufficient oxidant (hydroxyl radical) is available (Logan et al, 1980), except rarely in extremely polluted areas. Thus, reducing sulfur dioxide levels in the air is expected to proportionally reduce the sulfate formed by this pathway, and this is borne out by both field experiments (Cox and Penkett, 1970) and by regional observations (Eldred et al, 1981), as described in section 1) above.

For the second pathway ("oxidation in cloud droplets"), the relevant oxidant (hydrogen peroxide) is known to be ubiquitous in the atmosphere, but accurate measurements of its abundance have not been made. It has been suggested that current levels of sulfur dioxide emissions might overwhelm the levels of oxidants in the air, so that the air was "saturated" with sulfur dioxide. On this view, increasing sulfur dioxide emissions would not increase the formation of sulfate, and decreasing sulfur dioxide would not immediately decrease the formation of sulfate. However, no evidence has been presented to date that sulfate formation is limited by levels of oxidants, rather than by the levels of sulfur dioxide in the air. Considerable circumstantial evidence suggests the opposite -- that the air is not currently "saturated" with sulfur dioxide, and that the level of sulfate formation does indeed closely reflect the level of sulfur dioxide emissions. Some of this evidence is described below.

3) Studies of sulfur budgets (e.g., Galloway and Whelpdale, 1980) indicate that most of the sulfur dioxide that is *available* to be oxidized *is* oxidized to sulfate. It is not possible, e.g., for there to be two or three times more sulfate in precipitation than is now observed, given the current level of sulfur emissions, and taking into account the amount of sulfur blown outside U.S. borders, the amount of sulfur that is dry deposited, and the estimates for the rates of sulfur dioxide oxidation. This suggests that the air is not saturated with sulfur dioxide. Furthermore, individual rainstorms have been observed with very high sulfate levels -- 30 to 40 times higher than the average sulfate level in rain, and historical records document extremely high average sulfate levels in areas with very high sulfur emissions (Smith, 1872). This suggest that current emissions levels, as high as they are, are not saturating.

4) The clear and consistent association between high sulfur emissions in a region and high sulfate levels downwind, argues strongly against any significant saturation.

For example, in Fig. 1, discussed above, much less sulfate comes from the Great Lakes sector -- a low emissions region -- than from the high emissions sectors flanking it (Ohio Valley and Sudbury).[3] Such observations strongly suggest that reducing sulfur emissions from high source regions will reduce sulfate downwind.

In any event, even if there were a "non-linearity" in one of the pathways for sulfate formation, that would not be of significance to the current Hearing, for a number of reasons:

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[3] And this disparity must be even greater than indicated in Figure 1, since some sulfur dioxide from the high emissions sectors will have spilled over into the Great Lakes sector, tending to "flatten" the curve.

1) The *majority* of sulfur deposited in the Eastern United States is deposited by pathways that are *proportional* to the level of sulfur dioxide in the air. This includes dry deposition, which has been shown to be proportional to the level of sulfur dioxide in the air (Judeikis and Stewart, 1976), and which contributes at least as much to acid deposition as does "acid rain."[4] It also includes the gas-phase oxidation of sulfur dioxide to sulfate, discussed above, which also contributes significantly to acid deposition.[5]

2) Any lack of proportionality (or "non-linearity") in one pathway for sulfate formation must be compensated for by other pathways for sulfate formation.

For example, if reducing sulfur emissions led to a *less* than proportional reduction of sulfate formed in cloud droplets, then there would be a *more* than proportional reduction in ambient sulfur dioxide levels. This would produce a *more* than proportional reduction in sulfate formed by gas-phase oxidation. In addition, there would be a more than proportional reduction in dry deposition of sulfur dioxide.

3) The *effects* of acidity in the environment are *more than proportional* to the amount of acid added to the environment.[6] Even a small addition of

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[4] For an average concentration of sulfur dioxide of 10 micrograms/cubic meter and using the widely accepted "deposition velocity" for sulfur dioxide of 1 centimeter/second, dry deposition must contribute the equivalent of about 4.5 grams of sulfate per square meter per year. This is more than the amount of sulfate than falls in rain (typically 2 - 3 grams/square meter/year). Near urban regions, the level of sulfur dioxide in the air is significantly higher, typically 30 micrograms sulfur dioxide/cubic meter, and thus dry deposition will make an even greater contribution to acid deposition.

[5] Take a constant, steady-state ambient sulfur dioxide concentration of 20 micrograms/cubic meter. For a conversion rate of 1% per hour (Calvert et al, 1978), effective 6 hours/day, this is about 1 gram sulfate per square meter per year. (Since gas-phase oxidation can proceed at night as well, the true contribution of this pathway may be considerably higher.)

[6] This is a general property of buffered systems in which the buffer has been almost exhausted: a small addition of acid can cause a large increase in the acidity of the system. It holds true for vulnerable lakes and streams.

acid can cause a large change in the acidity of the environment. Therefore, ***even if*** a decrease in sulfur emissions caused only a disproportionately small decrease in the acidity of rain – and the evidence indicates this would not be the case -- it could still produce significant environmental benefits.

Recent claims that reducing sulfur dioxide emissions "might not" reduce acid deposition have been based on fallacious reasoning.

A frequent error underlying these claims is that factors *other* than sulfur dioxide emissions are allowed to vary, thereby confounding the influence of sulfur dioxide.

For example, Mohnen (1981) has cited the work of Granat (1978) in noting that an increase of roughly 50% in the sulfur dioxide emissions in Western Europe during the decade 1965 - 1975 did not lead to a proportional increase in wet sulfur deposition ("acid rain") in Western Europe. Mohnen invokes Granat's paper to "speculate that a reduction in sulfur dioxide emissions of as much as 50% in the entire Midwest might not result in any measurable change in deposition in the existing Northeastern U.S. network." This erroneous conclusion does not follow from Granat's work. Granat noted explicitly in his paper that the height of smokestacks increased substantially during this period, thus enhancing the long-range transport of sulfur *out* of the monitoring region, evidently to Eastern Europe. Thus one would not have *expected* to see a proportional increase in sulfur deposition in Western Europe.

Similarly, the JASON Report (1981) on acid deposition notes that sulfur dioxide emissions in the Eastern U.S. *decreased* slightly from 1960 - 1978 yet the acidity of rainfall in the Northeast apparently *increased* during this period. Again, *other* factors varied during this period. To cite two: The height of smokestacks increased markedly. (Patrick et al, 1981). This increased the average time that sulfur dioxide emissions remained aloft, and therefore increased the fraction of sulfur dioxide converted to sulfuric acid, thereby increasing the acidity of precipitation. In addition, large increases in nitrogen oxide emissions during this period *also* contributed to the increasing acidity of precipitation.

The JASON Report concludes that "a reduction in sulfur dioxide emissions *might not* lead to a reduction in acid deposition unless nitrogen oxide emissions are also controlled." This statement means simply that increasing nitrogen oxide emissions could *offset* the benefits of reducing sulfur dioxide emissions. It has been erroneously interpreted to mean that for a *given* level of nitrogen oxide emissions, reducing sulfur oxide emissions might not reduce acid deposition -- a conclusion for which the JASON Report presents no evidence.

In short, it is easy to draw erroneous conclusions when factors other than sulfur dioxide emissions are allowed to vary.

IS MORE INFORMATION REQUIRED?

The current body of scientific evidence concerning the the emission, transport, transformation and deposition of sulfur is, in my judgment, wholly sufficient to inform the policy decisions before the Committee.

It is possible to have a very good understanding of the overall behavior of a system *without* having a complete understanding of its microscopic workings. For example, we can predict quite well what the annual rainfall in Washington, D.C will be this year, even though we have no idea whether it will rain exactly three weeks from today. We know unequivocally that smoking causes cancer, even though we don't know the detailed chemical mechanisms involved.

In the same way, we know from the available evidence that regions with high sulfur emissions, particularly the Ohio Valley, contribute the most to acid deposition downwind, and we know that reducing sulfur emissions will substantially reduce acid deposition.

If the Committee decides that the effects of acid deposition warrant further control measures on sulfur emissions, it may be confident that a reduction in sulfur emissions will produce a commensurate reduction in acid deposition downwind.

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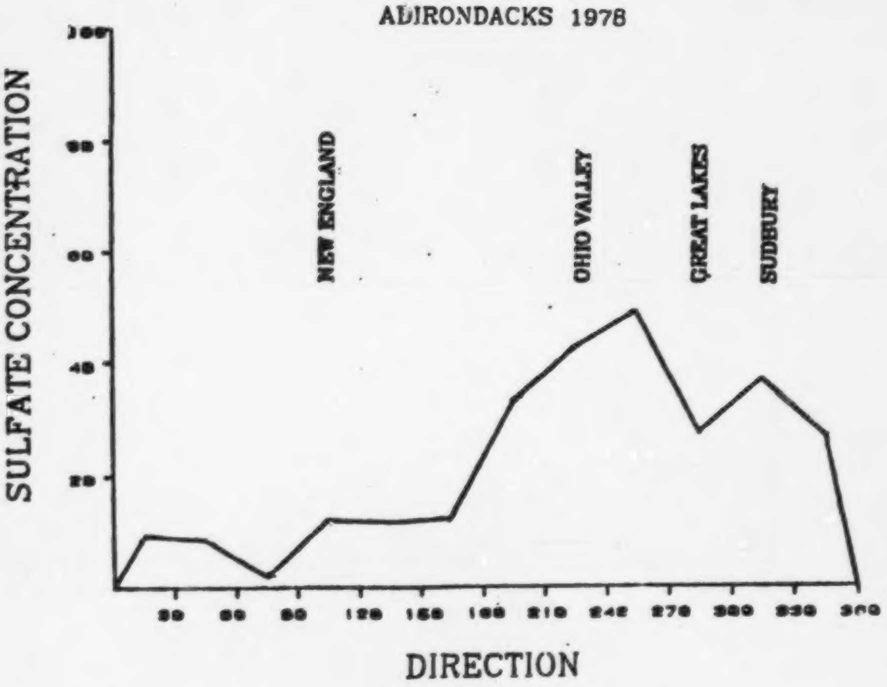

Figure 1. The average sulfate concentration in rain and snow brought to Whiteface Mountain, N.Y. by air masses from twelve sectors. (In micromoles/liter. 0-degrees is North.) Data from Wilson, Mohnen and Kadlecek (1980).

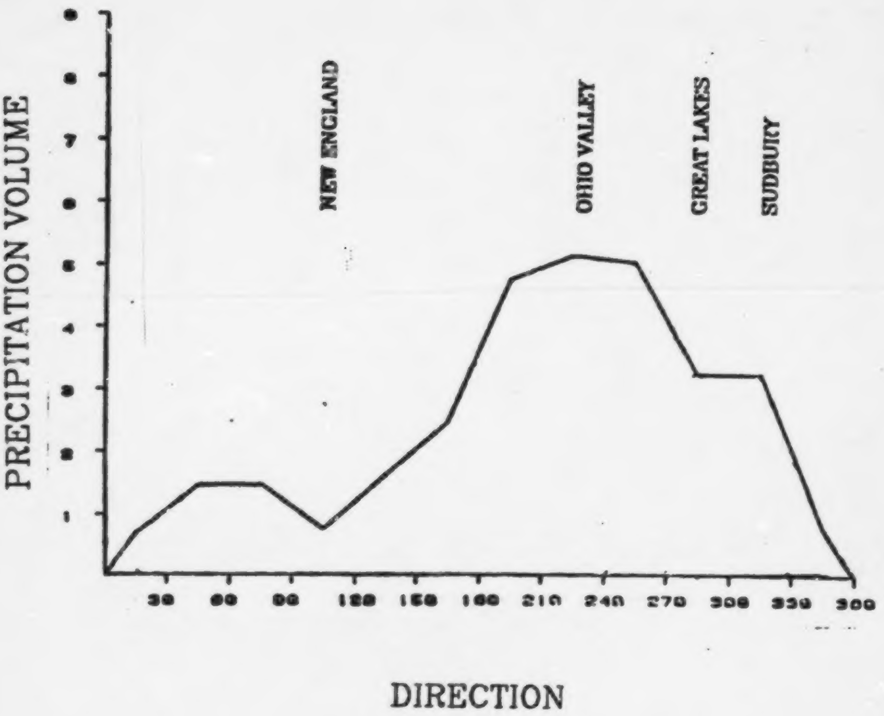

Figure 2. Precipitation brought by air masses from twelve different sectors to Whiteface Mountain, N.Y. for 1978. (Precipitation in liters.) Data from Wilson, Mohnen and Kadlecek (1980).

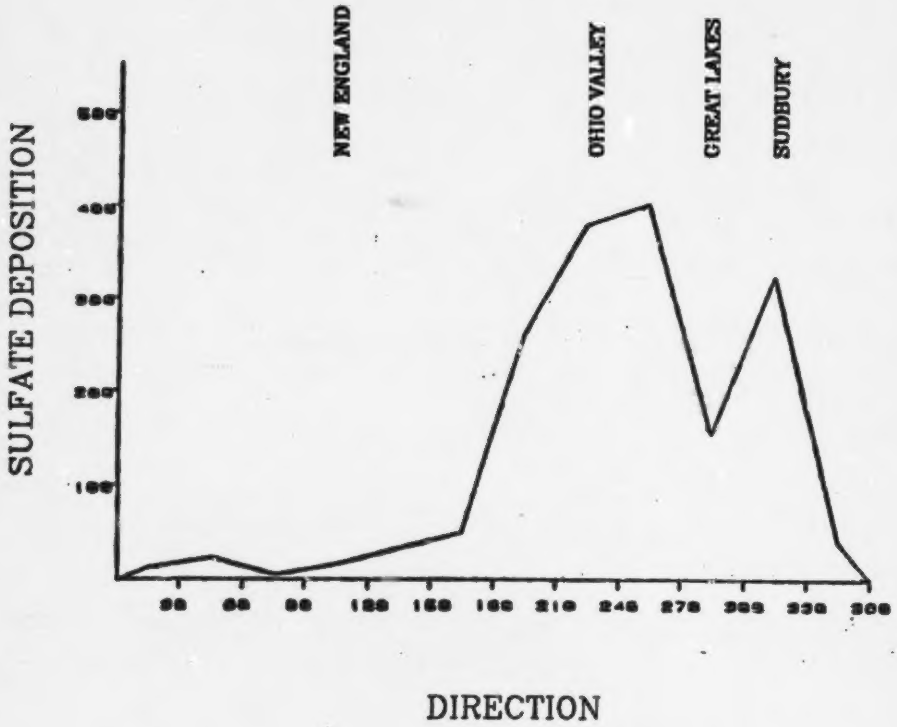

Figure 3. Sulfate deposited by rain and snow coming from twelve different sectors to Whiteface Mountain, N.Y., for 1978. (In milligrams/meter^2). Data from Wilson, Mohnen and Kadlecek (1980).

STATEMENT OF BRUCE HICKS

Prepared for Consideration of the Senate Committee
on Environment and Public Works. Technical Enquiry
on the Chemistry and Meteorology of Acid Precipitation

MODELING

The current state of knowledge concerning many of the processes involved in transporting and depositing atmospheric pollutants is exceedingly poor. In some cases, it is not even certain that the most important processes have been properly identified, let alone adequately studied. Thus there is considerable insecurity about many of the models that have been used to investigate source/receptor relationships. However, it must be appreciated that model development follows a logical sequence of development, testing, and improvement. This process is necessarily slow, and involves experimentalists and theoreticians as well as modelers. As a result of recent concern about air quality, many excellent atmospheric transport simulations have been developed. These are mainly applicable over relatively short ranges. It is now required to extend them to much longer distances, and to include accurate deposition formulations describing both dry and wet mechanisms in a rational yet relatively simple manner.

Over short distances, transport and dispersion models can be simplified because meteorological conditions can be taken to be constant. At the other extreme, simple models are often adequate when dealing with extremely long range effects, over continental or global scales, because the time scales are so long that averaged meteorological conditions can be used. However, over travel times longer than about six hours and shorter than several days the consequences of meteorological variability cannot be avoided. The diurnal cycle of winds, temperature, humidity, etc., in the lower atmosphere must be taken into account. Moreover, synoptic meteorology must be considered, since pollutant concentrations build up in stagnant air masses, precipitation is associated with frontal situations, and different kinds of rainfall scavenge pollutants at different rates.

The complexities of these meteorological factors (and the additional complexity of variable chemical reactions) are such that attempts to model regional-scale deposition of pollutants on an event basis are still in the early stages of development. Fortunately, many of the questions that are being asked of the models do not require hour-by-hour (or even day-by-day) answers If averages constructed over many synoptic cycles are considered adequate, then models that describe complicated atmospheric features in statistical terms can be quite useful. These statistical models exist in several different forms, and some of them have already been applied with considerable utility. However, any of these models is likely to be an air pollution model upgraded by the addition of some relatively simple deposition parameterization. If the intent of the model is to look at the impact on some selected kind of receptor, then it is clear that the deposition parameterization employed must take into account any peculiarities of the receptor region in question. Thus, we need to couple detailed deposition models with air pollution models, but as yet these deposition models are still being developed.

"Receptor models" are favored by many workers. These are statistical methods that look at the detailed composition of air contaminants at some location and try to explain the observations in terms of the known emissions from possible sources. It is assumed that the materials studied are all transported in exactly the same way, and that they are not transformed or generated during the travel. This assumption is somewhat limiting. It means that the method should be used with extreme care over regional-scale distances.

CLOUDS, AND WET DEPOSITION

Airborne particles are removed by falling raindrops below cloud base by much the same physical processes as those by which cloud droplets scavenge particles within clouds. However, there are other mechanisms (such as nucleation) that act to make in-cloud scavenging much more efficient than sub-cloud. Care must be taken about how to interpret field observations and how to represent these in models. The results of a study of washout of particles by raindrops falling through a smokestack plume will not be applicable to the case of long-range transport.

Early studies of radioactive fallout showed that clouds are highly efficient scavengers of airborne pollution, both gaseous and particulate. In the case of acid rain, it is becoming increasingly clear that in-cloud reactions can contribute considerably to precipitation chemistry. Gaseous sulfur dioxide in air can enter clouds, interact with other chemical constituents (e.g. nitrogen oxides), and be deposited as sulfate. In this regard, clouds can be thought of as sites for accelerated chemical reactions, regardless of whether they rain. Those clouds that do not rain leave the results of their chemical activity behind, as aerosol particles available for dry deposition and for wet deposition in subsequent rainfall systems.

The overall effect of clouds that do not rain yet chemically transform airborne pollutants is not well understood. The matter is likely to be rather important, since most clouds do not rain.

DRY DEPOSITION.

Precipitation delivers pollutants to the surface in relatively short but intense bursts. Dry deposition is a slower but more continuous phenomenon. The rate of dry deposition of any particular species is strongly affected by atmospheric conditions, by the nature of the surface and of the depositing material, and by concentrations of material in air near the surface. Average dry deposition fluxes to selected surfaces are usually calculated from airborne concentrations by applying a constant of proportionality, a so-called deposition velocity. In fact, this "constant" varies over wide extremes, and determination of appropriate average values is quite difficult. There is general agreement on values appropriate for most of the important cases (sulfur and nitrogen oxides), however there remains considerable disagreement for particles, especially for rough surfaces like forests. However, even in this case the difference between opposite viewpoints is rapidly narrowing. Whereas differences between different workers used to amount to factors of ten or more, factors of three now seem more typical.

The particles involved in the dry deposition of acidic material are very small, usually less than one micron diameter. It is accepted by most workers that dry deposition rates of submicron particles cannot be measured using the simple techniques (buckets, etc.) used in classical studies of dustfall. Many strong statements have been made about the utility of artificial deposition surfaces such as teflon plates, and it is sometimes claimed that dry deposition cannot be measured at all. This statement is wrong. There exist several meteorological methods by which measurements can be made, and there are special circumstances in which the rate of accumulation at the surface can be documented directly (for example, to snowpacks and washed foliage). Such measurements involve very detailed and intensive experimental techniques that are not presently suitable for use in routine monitoring. Instead, it is preferred to apply the results of these special case studies to infer dry deposition rates from data that can be readily monitored.

At this time, field experiments are agreeing well on the values of deposition velocities appropriate for the deposition of most of the materials relevant to the acid deposition question. Our understanding of the underlying physics and chemistry is lagging.

Because dry deposition rates are controlled by air concentrations near the surface, dry deposition of emitted gases like sulfur and nitrogen oxides tends to be highest nearest sources. However, particles are formed as these gases drift downwind and these particles then contribute to the net dry deposition of acidic material. In some locations, concentrations of particulate sulfur often exceed concentrations of gaseous sulfur. These particles are also likely to be associated with ammonia compounds, which constitute a further acidic input of ecological concern.

There is some lack of understanding of how radioactive fallout results compare with the present concerns regarding dry deposition of acidic materials. The radioactive fallout studies indicated that the vast majority of deposition was associated with precipitation scavenging. Recent studies of acid deposition suggest roughly equal apportionment between dry and wet deposition. The difference between the two situations is that radioactive fallout was held in an effective reservoir in the upper atmosphere, from which it slowly diffused downwards to the surface through the layer of the atmosphere in which precipitation originates. On the other hand, acidic pollutants and their precursors are injected directly into the lower atmosphere, where they are in much closer contact with the surface, and eventually diffuse upwards to become available for precipitation scavenging by clouds.

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STATEMENT OF

JOHN R. HOLMES, Ph.D.

Mr. Chairman and Members of the Committee:

For the record, my name is John R. Holmes. I am Director for Research for the California Air Resources Board. I am a chemist and have been professionally active in the field of atmospheric chemistry since 1969. A substantial portion of the research program I direct has been devoted to laboratory and field studies of the transport and transformation of air pollutants within the borders of our state.

When I appeared before this Committee last October, I described the results of our research on acid rain in California in some detail. I don't think I need to repeat those findings here today. But, by way of an update, some additional work by Caltech scientists this winter and spring has confirmed our earlier results — that rain in the Los Angeles area is strongly acidic and that nitrogen oxides, rather than sulfur dioxide, are the principal cause of the acidity. In addition, they have found that fog and stratus clouds in Los Angeles have pH readings as low as 2.2 — four times more acidic than the most acidic rain samples we have and nearly 3000 times more acidic than unpolluted fog. At this pH, fog causes rapid corrosion of steel and other construction materials and irritates the eyes, nose and throat. Further details on this work can be found in the supplemental material I have provided to the Committee staff.

In California, the Governor, the Air Resources Board and concerned Legislators are determined to prevent the kind of environmental damage that has occurred in the Northeast. A bill that will authorize our Board to carry out an accelerated research program and establish additional regulations, as necessary, to limit acid deposition is now moving through the Legislature. Its chances for passage appear to be excellent.

Today, we have been asked to address specific questions about acid deposition in the northeastern U.S.

First, what is the probability that substantial reductions in the emissions of acid precursors will lead to correspondingly large reductions in acid deposition? My short answer is: very high.

California has had an ambient air quality standard for sulfates and sulfuric acid for several years. So we measure sulfates in the air routinely. In Los Angeles, we also keep a daily record of sulfur emissions for major sources. These records go back to the sixties.

Atmospheric sulfate readings have tracked sulfur emissions very closely over the years. And the changes in emissions have been substantial, because the fuel supply has shifted between high-sulfur fuel oil, low-sulfur fuel oil and natural gas.

On the other hand, day to day sulfate measurements do not correlate well with sulfur emissions. This is because variations in meteorological factors and oxidation rates are much larger than short-term fluctuations in sulfur emissions.

But, protecting the environment from the ravages of acid rain is largely a matter of limiting the seasonal and long-term delivery of acidic sulfates to distant receptor sites. So I'm convinced, on the basis of what we've learned in California, that reducing sulfur emissions will, over the long term, lead to proportionate decreases in acid deposition in other parts of the nation. Many other scientists, of course, share this view (NAS/NRC, 1981).

For sulfur, the proportionality may be somewhat less than one to one, since it appears (Chamberlain, et al., 1981) that sulfuric acid formation is limited, under some conditions, by the ability of the atmosphere to oxidize sulfur dioxide. The same is true in Los Angeles.

But, interestingly enough, if the oxidizing power of the atmosphere is limited by the availability of nitrogen oxides in dilute urban plumes -- and most scientists believe that it is -- then raductions in the emissions of nitrogen oxides would be expected to produce something more than a one to one decrease in atmospheric acidity.

As to the question of whether emissions controls in the Midwest would mitigate the acid rain problem in the Northeast, perhaps the others on the panel are better qualified than I to answer. This is fundamentally a question of meteorology and climatology, and I can claim no special expertise in this area.

But I am aware of a number of studies (see, for example: Miller, et al., 1978; Parekh and Husain, 1981; Thurston and Speugler, 1981; and Wolff, et al., 1979) that used both meteorological analysis and trace element data to demonstrate that high sulfates and high acidity in New York and the Northeast are associated with air parcels arriving from the southwest. Moreover these air parcels often exhibit the characteristic chemical signature of coal combustion products.

Certainly, there are going to be day to day, week to week and seasonal variations in the amount and sources of the acidity delivered to the Northeast. But clearly, over the long haul — and, again, thats what we're interested in -- controls applied in urban-industrial areas to the south and east, including the Midwest, will substantially reduce the severity of the problem.

Tall stacks, while they reduce the concentration of pollutants in the immediate vicinity of power plants, also spread out pollution over a wider area. For a single, isolated facility, perhaps this approach is defensible. But, for large numbers of facilities that are relatively closely spaced relative to the transport distances -- such as we find in the eastern third of the country -- tall stacks are definitely not the solution. They *increase* the time available for transport and oxidation to the acidic form and *decrease* the opportunity for acids to be neutralized by the ammonia and alkaline dusts that are concentrated near the surface. And lateral dilution soon becomes a matter of plumes mixing with other rather than clean air.

It seems clear enough to me that climatological factors point to a multiplicity of sources to the south and west as being responsible for the high levels of acidity observed in precipitation in the Northeast. I think the time to act to reverse this trend is now, not later.

What actions can be taken now? Most important, Congress can hold the line on NOx controls for cars. This will have a two-fold benefit: first, it will reduce the amount of nitric acid in precipitation; second, it will reduce the capacity of the atmosphere to oxidize both sulfur dioxide and nitrogen oxides to their acidic forms. Proven technology to reduce NOx emissions to well below one gram per mile is readily available at relatively low cost. Relaxing the standard will provide little benefit for either the automobile industry of the consumer.

A wide range of sulfur control options is also available. Coal can be crushed and washed; fuel oils as well as gasoline and diesel fuel can be desulfurized; and practical flue-gas scrubbering techniques have developed and demonstrated. The costs here vary, depending on the fuel, the faciltiy and other factors. But surely a cost-effective mix of these options can be put into place within the decade.

Control of nitrogen oxides from stationary combustion is a developing technology. Demonstration units are operating in this country; full-scale units have been operated successfully for the past several years on oil - and coal - fired power plants in Japan. There is no reason to believe that such units cannot be brought on line in this country during the eighties.

Regulating in the absence of full and complete scientific knowledge is fully justified, it seems to me. We've done it in California with photochemical study, and it's worked. Strategies have been fine tuned over years as a result of research. But the basic approach remains unchanged. With acid rain in the Northeast, especially, the probable consequences of doing nothing for another five or ten years are simply unacceptable. To delay action would, I think, be utterly irresponsible.

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Appendix A

CHEMICAL COMPOSITION OF ACID FOG

by

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Richard C. Flagan, James J. Morgan, and Michael R. Hoffmann*

ABSTRACT

Fog water collected in Los Angeles and Bakersfield, California was found to have higher concentrations of major chemical components than previously observed in atmospheric water droplets. The pH of fog water was found to be in the range of 2.2 to 4.0. Dominant processes controlling the fog-water chemistry appear to be condensation and evaporation of water vapor on pre-existing aerosol and scavenging of gas phase nitric acid.

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*To Whom Correspondence Should be Addressed

In the fall of 1981, a field study was initiated to determine the chemical composition of fog water in the Los Angeles basin. Results show that the fog water is significantly more acidic and concentrated with respect to chemical composition than cloud and rain water collected in Southern California. Earlier, Liljestrand and Morgan (1) determined the chemical composition of rain in Los Angeles and reported that light, misting rainfalls had the highest acidity (2). Previous fog water studies (3) in non-urban environments have reported concentration levels of major ions comparable to those reported for cloud (4) and rain (5) water. However, urban fogs tend to form under more polluted conditions than clouds. The present research program expands upon these previous studies in an attempt to focus on the chemical and physical processes that occur in the atmospheric aqueous phase before a precipitation event. In the Los Angeles basin fog and cloud water processes may represent a significant pathway for SO_2 and NO_x oxidation and for the concomitant production of acidity. Furthermore, morning fog and low clouds along the coast have been strongly correlated with high sulfate aerosol concentrations during the afternoon in the Los Angeles basin (6).

In this study, fog water was collected with a rotating arm collector (7). Droplets impact in slots along the ends of the arm and are driven outward by centrifugal force into sample collection bottles which serve effectively to isolate the collected liquid. In cloud chamber tests, the lower particle size cutoff for this collector was estimated to be 8 μm. Two of the collection sites were located in the Los Angeles basin (Pasadena and Lennox) and the third was located in the San Joaquin Valley near Bakersfield. The Pasadena site was located in a residential neighborhood 25 km from downtown Los Angeles;

the Lennox site was located 2 km from the Los Angeles International Airport adjacent to a freeway and near two power plants and one oil refinery; and the site in the San Joaquin Valley was located in Oildale, which is surrounded by secondary oil recovery operations.

Concentration ranges of major chemical components observed during five separate fog events are listed in Table 1. These ranges represent the low and high values measured in time-sequenced samples over the duration of the particular fog events (8).

The first fog event in Pasadena followed a day with good air quality; the second fog event was preceded by a hazy day. Concentrations of most ions in the latter fog water were much higher than in the first fog event. The third fog event was sampled in Lennox on the second night of dense coastal fog. Smog and dense haze had persisted throughout the preceding day, accompanied by high ambient NO_x concentrations along the coast. These samples had even higher concentrations than the Pasadena fog samples. In addition, the fog water contained a significant amount of solid material, especially in the final sample taken as the fog dissipated. Most of the particles remained suspended in the samples after standing several days, which suggests that they were too small to have been collected unless incorporated in larger droplets.

A single fog event in the San Joaquin Valley at Bakersfield was monitored during a period of extended fog throughout the entire valley. The southern portion of the San Joaquin Valley has a number of oil fields in which steam injection, oil recovery methods are used. Consequently, the sulfur emissions are high for a non-urban, agricultural area. The fog-water analyses, which were characterized by low pH values (pH 2.9) and high SO_4^{2-} (5.0 meq/L), NO_3^- (5.1 meq/L) and NH_4^+ (11.8 meq/L), reflect the dichotomous land use in the San Joaquin Valley.

Finally, a single fog-water sample was collected on the night of 17 January 1982 in Pasadena. The pH of this sample (pH 2.25) was unusually low with correspondingly high levels of NO_3^- (12 meq/L), SO_4^{2-} (5 meq/L) and NH_4^+ (8 meq/L); however, the duration of this final fog event in Pasadena was relatively short (~ 1 hr.).

Concentrations of major components in the California fog samples were significantly higher than in previously reported samples of fog, cloud and rainwater as shown for comparison in Table 1. In the case of SO_4^{2-}, NO_3^-, NH_4^+ and H^+, the observed concentrations were 10-100 times higher than the previously reported values. Concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^- were high but more in line with values reported for fog and cloud water in other areas. High concentrations of formaldehyde, iron, manganese and sulfite (30-260 μeq/L) were also found. Observed concentrations of S(IV) appear to be in excess of those predicted by Henry's Law considerations although formation of sulfonic acid derivatives and iron sulfito complexes can account for this apparent discrepancy (9).

Figure 1 illustrates changes in total ionic concentration with respect to time for three fog events. A concave trend in the concentration vs. time profile (decreasing at the beginning and rising toward the end) was observed. Changes in absolute concentration of individual ions that are proportional to the changes in total concentration indicate that water vapor condensation or evaporation of the fog droplets are dominant processes. Sharp decreases in concentration during the first few hours of the fogs in Lennox were due primarily to initial droplet deliquescence on pre-existing aerosol. Similarly, most of the increase in concentration that was observed as the fogs dissipated was due to evaporation and regeneration of fine aerosol. These physical effects apparently play a dominant role in determining fog chemistry in the Los Angeles basin.

The dominant ions in the fog water were NH_4^+, H^+, NO_3^- and SO_4^{2-}, and their highest concentrations were observed after days of dense haze. During the early phases of the Lennox fogs, these ions comprise $\geq$ 90% of the total ionic concentration. This suggests that pre-existing aerosol is a major determinant of the chemical composition of fog-water, since these four species are the major components of the daytime aerosol haze (10).

In Los Angeles, the NO_3^- to SO_4^{2-} equivalent ratio in fog water was about 2.5, which is comparable to the reported emission ratio (3). The corresponding ratio in Los Angeles precipitation was close to 1.0 (1). In the Bakersfield fog, the nitrate to sulfate equivalent ratio was approximately one.

The observed changes in fog-water composition may have resulted either from chemical changes in the droplets or advection of different air masses over the sites. In Pasadena, $[H^+]$ and $[NO_3^-]$ simultaneously increased as a function of time suggesting the transport of HNO_3 or N_2O_5 into the droplets (11). On 7 December in Lennox, $[NH_4^+]$ doubled from the third to the fourth sampling period while there was a corresponding decrease in $[H^+]$. Transfer of gaseous NH_3 into the droplets could account for this neutralization. However, the delay in the $[NH_4^+]$ increase after the onset of fog suggests that advection of fog formed on condensation nuclei with different characteristics was responsible. During the last few hours of that event, an increase in $[Ca^{2+}]$, $[Mg^{2+}]$ and [Fe] was observed. This increase coincides with the morning rush hour traffic on the adjacent freeway and can be attributed to the incorporation of road and soil dust into the fog. Finally, the fogs in Lennox started out with a high acidity that was progressively neutralized, while the fogs in Pasadena became more acidic during a fog event. This result suggests differences in the composition of the aerosol preceding the fog at each site and differences in gas or solid to liquid transfer characteristics.

In conclusion, results of this study have shown that concentrations of major chemical species in fog water collected in Los Angeles and Bakersfield are significantly higher than previously reported in atmospheric water droplets. The chemistry of fog water in Los Angeles appears to be dominated by the composition of the haze-forming aerosol that precedes it. Subsequent effects of condensation and evaporation control the observed concentration levels. Secondary aerosol, which has high NH_4^+, H^+, NO_3^-, and SO_4^{2-} levels, deliquesces initially to give a concentrated fog water. Further condensation of water results in dilution. After initial formation, the fog water appears to incorporate additional NH_3, HNO_3 and calcareous dust. As the fog dissipates due to evaporation higher concentrations are again observed.

In light of the inordinately high concentrations of acidic components found in Los Angeles fog, further research is needed to determine the role of aqueous atmospheric droplets in SO_2 and NO_x conversion and acidity transport processes. High levels of H^+, NO_3^- and SO_4^{2-} found in fog water may have a significant effect on health and on materials and plants in urban areas such as Los Angeles and non-urban areas such as Bakersfield.

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8. Immediately after collection, the pH of the sample was measured and aliquots were separated to be preserved for later analyses. Major metal cations were determined by atomic absorption spectrophotometry (AAS) and major anions by ion chromatography (IC). Ammonium ion and formaldehyde were determined by standard colorimetric methods. Addition of nitric acid (Ultrex grade) was used to preserve the trace metals; sulfite was stabilized by reaction with formaldehyde at pH 4.

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TABLE AND FIGURE CAPTIONS

Table 1. Ranges in ionic concentration observed during six fog events (8). Representative concentrations for other fog, cloud and rain samples are presented for comparison. The ranges shown in values for this study are from sequential samples during individual events with the exception of the sixth event. For comparison data, the ranges represent many events.

Figure 1. Ionic composition in serial samples collected during three Los Angeles fog events. The width of each bar represents the sampling interval. Fog formation and dissipation (i.e. beginning and end of individual fog events) are indicated by arrows. Fog had formed at least one hour prior to the first sample on 7 December 1981; sampling on 17 December 1981 was ended before the fog dissipated. The effect of dilution and concentration can be seen by the proportional changes in ionic concentration.

TABLE I

				μeq/L									mg/L		
Location	# Samples	Date	pH	H^+	Na^+	K^+	NH_4^+	Ca^{2+}	Mg^{2+}	F^-	Cl^-	NO_3^-	SO_4^{2-}	Fe	CH_2O	Reference
Pasadena	4	11/15/81	5.25-4.74	8.6-55	12-496	4-39	370	19-360	7-153	120	56-280	130-930	62-380	0.094-2.1	-	This study
Pasadena	4	11/23/81	4.85-2.92	14-1200	320-500	33-53	1290-2380	140-530	59-360	180-410	480-730	1220-3520	481-944	0.92-1.77	3.1-3.5	"
Lennox	8	12/7/81	5.78-2.55	2-2820	28-480	6-160	1120-4060	44-4350	17-1380	115-395	111-1110	820-4560	540-2090	0.34-24	4.6-12.8	"
Lennox	3	12/17/81	2.81-2.52	1550-3020	80-166	19-40	950-1570	73-190	43-99	180-500	90-197	2070-3690	610-1970	1.02-2.08	-	"
Bakersfield*	3	1/14/82	3.07-2.90	850-1260	151-1220	39-224	5370-10520	165-1326	20-151	126-242	203-592	3140-5140	2250-5000	-	6.1-14.4	"
Pasadena*	1	1/17/82	2.25	5625	2180	500	7870	2050	1190	637	676	12000	5060	-	-	"
Los Angeles Rain (vol wt means at 9 sites)		1978-79	5.4-4.4	4-39	4-37	0.24-4.9	1-36	3.9-17	1.7-11	-	5-52	11-44	7-56	.004-.17	-	Liljestrand & Morgan (1)
Coastal Calif. Fogs		9-10/76	-	-	78-944	8-26	1-578	9-102	17-175	-	96-1230	23-234	52-490	-	-	Mack and Katz (3)
Whiteface Mtn.		7-8/80	4.2-3.2	63-530	1-55	1-6	4-310	-	-	11-54	1-15	7-190	40-800	-	-	Falconer (4)
Fog & Clouds USSR		1961-64	5.3-4.7	5-20	30-104	15-44	33-100	20-50	17-83	-	59-177	2-13	13-185	-	-	Petrenchuk & Drozdova (3)

*$[Na^+]$, $[K^+]$, $[Ca^{2+}]$, $[Mg^{2+}]$, and $[NH_4^+]$ for filtered aliquots

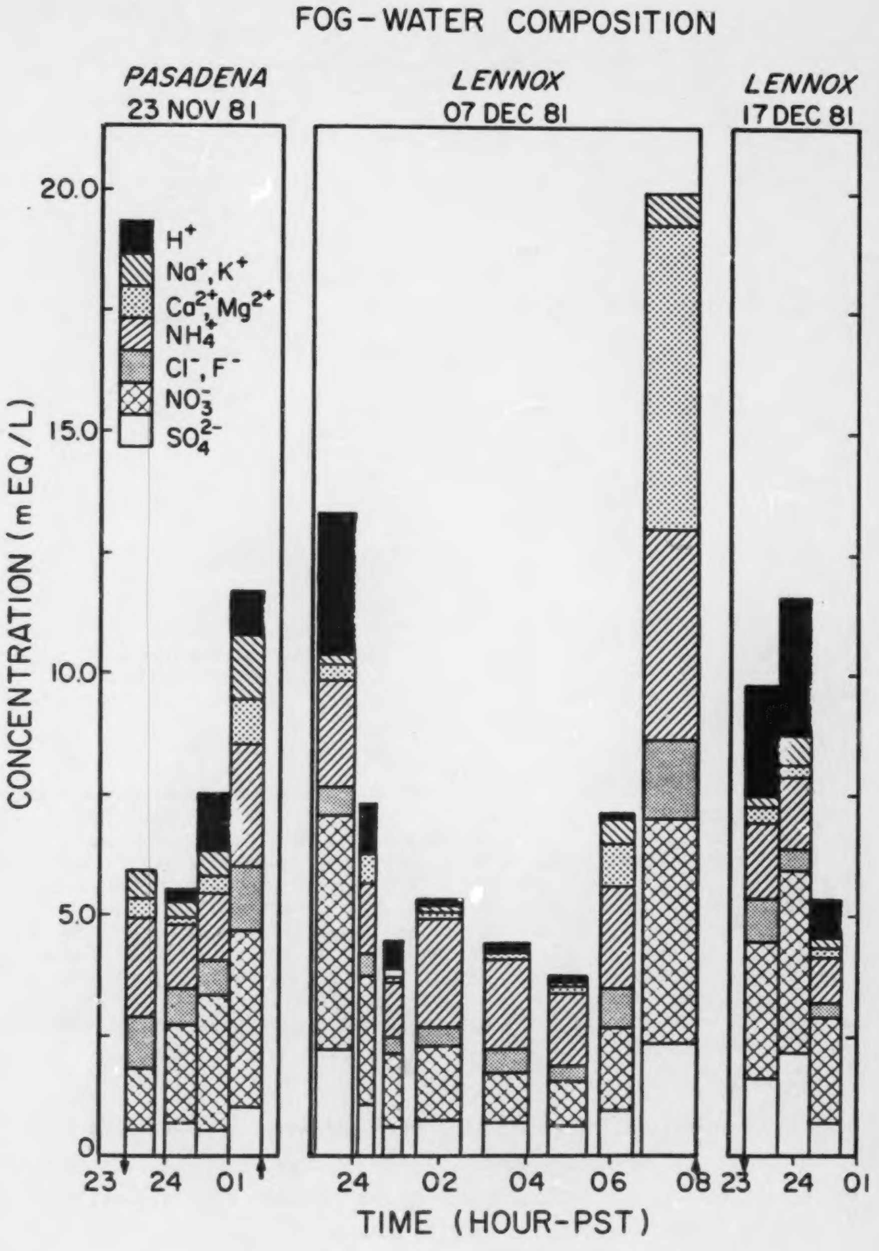
FOG-WATER COMPOSITION
PASADENA
23 NOV 81
LENNOX
07 DEC 81
LENNOX
17 DEC 81
CONCENTRATION (mEQ/L)
20.0
15.0
10.0
5.0
0
H+
Na+, K+
Ca2+, Mg2+
NH4+
Cl-, F-
NO3-
SO4 2-
23
24
01
24
02
04
06
08
23
24
01
TIME (HOUR-PST)

FIGURE 1

Appendix B

FACTORS GOVERNING THE pH, AVAILABILITY OF H^+, AND OXIDATION CAPACITY OF RAIN

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Abstract. The acidity of rain is coupled to redox reactions in air and in atmospheric water. The pH (intensive) needs in general to be distinguished from the base neutralizing capacity. For acid rain observed at most locations H_2SO_4, HNO_3, NH_3 and $CaCO_3$ are dominant components. Their local availability or production rates govern net acidity. pH is thus almost entirely determined by these major "strong" components, with some influence by $SO_2(aq)$, smaller concentrations of HNO_2 and weak organic acids and minor bases such as Fe_2O_3 and Al_2O_3. Total global emissions to the atmosphere of H_2SO_4 precursors outweigh those of HNO_3 by a factor 2-3 on an equivalent basis. In specific settings HNO_3 may be comparable to H_2SO_4 in rain. Total atmospheric acidity appears to be a useful quantity for estimating potential acidity of rain at different locations. There are indications in photochemical models of HNO_3 and H_2SO_4 that feedback among S and N species may be important. Heterogeneous oxidations of SO_2 in cloud, fog, and rain play important roles in the acidification process. "Background" acidities of rain appear to be highly variable; pH values are expected to range from below 5 to above 6. Present day SO_2 and NO_x fluxes account for a pH lowering of $\sim$ 0.5 to 1.5, depending upon source location and transport-conversion rates.

INTRODUCTION

Acidity (base-neutralizing capacity) and alkalinity (acid-neutralizing capacity) are complementary concepts. The acidity versus alkalinity balance of rain (and drizzle, snow, fog and clouds) is intrinsically coupled to oxidation-reduction reactions in the air and in atmospheric water. Sillén likened the geochemical evolution of the earth's atmosphere-ocean system to a set of gigantic, somewhat coupled acid-base and oxidant-reductant titrations in which the "volatiles", acids from the earth's interior (H_2O, HCl, SO_2, CO_2 and others) were titrated by bases from the rocks and in which reduced components (H_2, NH_3, Fe_3O_4, C) were titrated by the O_2 of the evolving atmosphere-biosphere system. As a result of such global and titrations we arrive at a present-day atmosphere which is 20% O_2, 79% N_2, and 0.03% CO_2, a world ocean with a pH of 8 and alkalinity of 2.3 meq/ℓ. The system is not an equilibrium, of course. It is an open one with high fluxes. Still, the titration metaphor may be useful in thinking about the state of the atmosphere-hydrosphere-biosphere system today, on global, regional and local scales. Evidence over the last century shows increased emissions of strongly acidic components and acidic precursors such as sulfur dioxide, sulfuric acid, hydrochloric acid, and nitric oxide to the atmosphere. Fossil fuel burning has also led to an increase of global atmospheric CO_2 by some 15%. These emissions, through photochemical and chemical reactions in the atmosphere, lead to an increase in the total acidity of the atmosphere and consequent increases in local and regional fluxes of acidity to the earth's surface through rainfall of increased acid content and lower pH (wet deposition) and through absorption and fallout of gases and aerosols (dry deposition). Present fluxes of acidity and possible future increases have important implications for aquatic and terrestrial ecosystems, water resource systems, weathering of natural and man-made environments, and for the longer-term chemical state of atmosphere-water systems locally and regionally, if not globally.

Concepts of H^+ Availability and Acidity

Aqueous acids are proton donors; aqueous bases are proton acceptors. The "strong" acids, e.g., HNO_3 donate protons to water essentially completely.

$$HNO_3 + H_2O \longrightarrow H_3O^+ + NO_3^-$$

the equilibrium acidity constant is the measure of strength. Here, $K_{a,HNO_3} > 1$ for the standard state conventions adopted. Aqueous CO_2 is a weak acid. The reaction

$$CO_2(aq) \rightleftharpoons H_3O^+ + HCO_3^-$$

has an effective acidity constant which is $K_{a,CO_2} = 10^{-6.4}$ at 25°C. Bases, e.g., OH^- ion, CO_3^{2-} ion or NH_3 are similarly strong or weak. For example, the strengths of OH^-, CO_3^{2-} and NH_3 as bases can be ranked by their acceptance of aqueous protons (17)

$$OH^- + H_3O^+ = 2H_2O$$
$$CO_3^{2-} + H_3O^+ = HCO_3^- + H_2O$$
$$NH_3 + H_3O^+ = NH_4^+ + H_2O$$

with respective equilibrium constants $10^{14} > 10^{10.3} > 10^{9.2}$ at 25°C.

The properties of a given aqueous acid are readily linked to those of related components in the gas phase or in solid phases by appropriate two-phase constants, e.g., Henry's law and solubility equilibrium constants. Similarly, acids and bases are derived from precursors via oxidation-reduction processes.

The four key concepts which define the resultant acid-base characteristics of rain are: (i) energetics, i.e., equilibrium properties of component acids and bases and acid-base precursors, e.g., redox components; (ii) the total acid or base neutralizing capacity with respect to some proton reference level, i.e., a specified acid-base solution, e.g., CO_2 in H_2O; (iii) the aqueous proton concentration, $[H_3O^+] \equiv [H^+]$, or activity, $\{H^+\}$, which are related intensity factors, representing the free aqueous protons or immediately available protons, (Bates (1) refers to proton activity, proton availability, and degree of acidity synonymously); (iv) kinetics of reactions and transfer processes leading to production of acids or bases in rain.

It is essential to distinguish between the free aqueous proton and the base neutralizing capacity, or reservoir of ultimate H^+ availability. These notions can be illustrated by means of simple examples for various component acids at concentration levels like those in rain. A group of acids of varying strengths (see Figure 3, further on) and concentrations have been selected. Initial pH values (neglecting minor activity coefficient corrections) and base neutralizing capacities have been calculated. No redox changes have been assumed. The solution is closed to the atmosphere. The results are shown in Table 1.

Some points can be noted. Comparing equimolar (10 μM) solutions one at a time we see that pH values range from 4.7 (H_2SO_4) to neutral for the very weak acid NH_4NO_3, whereas the total acidity (TOTH) is the same on an

TABLE 1. Available H^+ (pH) and Base Neutralizing Capacities of Dilute Acid Solutions.

Acid	Conc µM	pH (25°C)	Base Neutralizing Capacity µeq ℓ^{-1}	
			to pH	BNC[#]
H_2SO_4	10 50	4.7 4.0	7.0 7.0	20 100
HNO_3	10 50	5.0 4.3	7.0 7.0	10 50
SO_2(aq)	10	5.0	6.1 8.1	10 20[‡]
CH_3COOH	10 50	5.1 4.7	7.1 7.3	10 50
NH_4NO_3	10 50	7.0 6.8	8.9 9.4	10 50
CO_2	10	5.7	7.6 9.0	10 20[‡]

[#] BNC with respect to least-protonated level is also known as TOTH. [‡] Least-protonated level of weak diprotic acid.

equivalent basis (H_2SO_4, SO_2 and CO_2 are diprotic). It is evident, as remarked by Odén (14), that, for strong acid solutions (e.g., H_2SO_4 and HNO_3), concentrations of these acids determine the pH value, hence the H^+ activity or availability. For a weak acid such as CH_3COOH, with $pK_a = 4.7$, a dilute solution leads to extensive dissociation and pH 5.1. If CO_2 at 10 µM is titrated to pH ∿ 9, 20 µeqℓ^{-1} of acidity will be measured. We notice that SO_2 with $pK_a = 1.8$ is effectively a "strong" acid at these concentrations.

At five-fold higher concentrations of H_2SO_4, and HNO_3 and CH_3COOH pH is lowered considerably in each case. If acids were mixed at these higher concentration levels, the resulting pH would be approximately 3.8. The CH_3COOH dissociation would contribute only about 6 µeqℓ^{-1} to the free acidity (available protons). The NH_4NO_3 contributes nothing. The base neutralizing capacity with respect to a CO_2/H_2O two phase system (CO_2 = 10 µM) would be 195 µeqℓ^{-1}. Were NH_3 rather than NH_4NO_3 introduced, the basicity of NH_3 would lead to the reaction $NH_3 + H^+ = NH_4^+$ and the acidity would decrease by 50 µeqℓ^{-1}, the pH rising to almost 4.0. However, if the NH_4NO_3 were oxidized to HNO_3 (as in a receiving ecosystem): $NH_4^+ + 2O_2 \rightarrow 2H^+ \; NO_3^- + H_2O$, the total acidity would increase by 100 $\mu eq\ell^{-1}$, increasing the base neutralizing capacity with respect to CO_2/H_2O by about 50%. If H_2SO_4 were reduced (as in an anoxic sediment environment) to H_2S ($pK_a = 7$), the base neutralizing capacity towards CO_2/H_2O would decrease by about 50%. Oxidation of all the CH_3COOH to CO_2 would decrease BNC by 35 $\mu eq\ell^{-1}$ with respect to a CO_2/H_2O reference level. Finally oxidation of SO_2: $SO_2 + \frac{1}{2} O_2 \rightarrow H_2SO_4$, increases the BNC towards CO_2 by 10 $\mu eq\ell^{-1}$, lowering pH somewhat but leaving TOTH unchanged.

ACIDITY, ALKALINITY AND pH

The earliest known quantitative description of the chemistry of rain and its acidity was given for the United Kingdom by Smith in his book Air and Rain, in 1872 (5). His analysis included acidity as (H_2SO_4), ammonia, nitrate, sulfate, chloride and organic matter. Arrhenius' theory of electrolytic dissociation came 15 years later; Smith's acidity corresponded to, roughly, $[H^+]$ of 200 μM. Sorenson introduced the pH scale in 1909; Smith's rain had a pH of perhaps 3.7. Thinking in terms of the components required to make the rain which Smith analyzed at Manchester (5) we could choose H_2O, H_2SO_4, HNO_3, HCl, NH_3, $NaCl$ and Na_2SO_4 (the latter two for the marine component). The approximate charge-balance relationship in the rain water would than be (anticipating Arrhenius): $[H^+] + [NH_4^+] + [Na^+] = 2[SO_4^{2-}] + [NO_3^-] + [Cl^-]$. We now recognize that this chemical balance is incomplete. Later rainfall analyses reported by Gorham (4), Junge (8), and Granat (6, 7) make it clear that the following ten ions are nearly always found in rainfall in significant concentrations, the relative importance depending on provenance: SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+} and H^+. Table 2 shows ion concentration data and pH for acidic rainfall at three locations. At Pasadena, titration with base confirms that free acidity $[H^+]$ and that TOTH is $[H^+] + [NH_4^+]$, plus ∿ 1-2 $\mu eq\ell^{-1}$ of unidentified weak acids (probably metal ions and organic acids).

Observations on the major ions of rain at many locations for the past several decade suggest a universal set of input components which account for the net acidity, pH and resulting chemical species in most rain. Recent observations on rainfall chemistry at different locations in the

TABLE 2. Chemical Analyses of Acidic Rain at Three Locations.

Species	Concentration μeq^{-1}		
	Sjoangen, S. Sweden[a]	Hubbard Brook, New Hampshire[b]	Pasadena, Calif.[c]
SO_4^{2-}	69	110	39
NO_3^-	31	50	31
Cl^-	18	12	28
NH_4^+	31	22	21
Na^+	15	6	24
K^+	3	2	2
Ca^{2+}	13	10	7
Mg^{2+}	7	32	7
H^+	52	114	39
pH	4.30	3.94	4.41

a, 1973-75 (7); b, 1973-74 (10); c, 1978-79 (12).

Los Angeles basin of southern California (Figure 1) provide a convenient illustration of variations in components. The ratio of $[SO_4^{2-}]$ to $[NO_3^-]$ on an equivalent basis ranges from 1.5 at Westwood (6 km from the Pacific coast to 1.1 at Pasadena (40 km inland) to 0.9 at Riverside (70 km inland). The coast is where the majority of fossil-fuel burning stations are sited. Qualitatively similar variations in composition are seen over far greater distances in Northern Europe and the Eastern United States.

A set of components that accounts for observed net acidity or alkalinity of rainfall at European stations was proposed by Granat (6). Figure 1 illustrates application of the concept in terms of the "components" strong acids, sea salt, soil dust, and ammonia. The corresponding chemical components could then be (consistent with Table 1 and Figure 1): NaCl, KCl, $MgSO_4$, $CaCO_3$, NH_3, H_2SO_4 and HNO_3. While this choice of acid-base-salt components accounts for the commonly-reported chemical analyses, it is not a realistic choice in terms of ultimate sources of acidity or

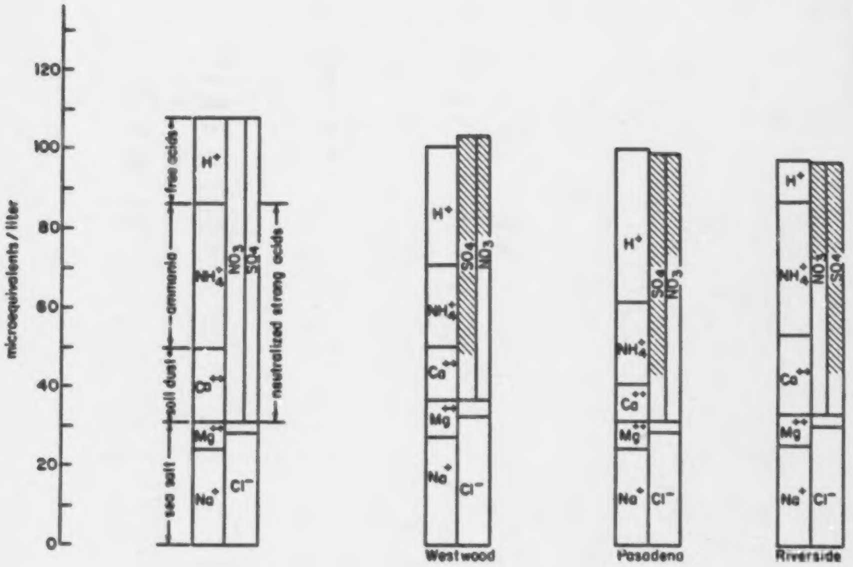

FIG. 1. Composition of Rain in Southern California, 1978-79, Interpreted in Terms of Input Components and Source Type. (Coast → Inland, left → right; widths of SO_4^{2-} and NO_3^- bars indicate relative amounts; cross-hatchings indicates stationary sources, non-hatched, mobile) (2).

alkalinity in rain or in terms of gas phase, aerosol, or aqueous phase species already identified in transport and transformation processes leading to acidification of rain. In the absence of significant anthropogenic emissions, H_2S is a major precursor for H_2SO_4 formation in the atmosphere (organic sulfur compounds are also a smaller part of the natural background). For nitrogen the principal natural and anthropotenic precursor of atmospheric and rainfall acidity in nitric oxide, NO, when grouped together with NO_2, referred to as NO_x. The dominant man-made precursor emission of sulfur is sulfur dioxide, SO_2. Interplay of acid-base (proton transfer) and oxidant-reductant (electron transfer) reactions in air and water is better accounted for by the emission components: NaCl, KCl, $MgCl_2$, $MgSO_4$, $NaHCO_3$, $CaCO_3$, NH_3, HCl, H_2S, RS, SO_2, H_2SO_4, and NO. In the oxidizing atmosphere H_2S, RS and SO_2 are transformed to H_2SO_4 (with characteristic times ranging from less than a day to weeks, depending on chemical and physical conditions in the atmosphere). Both homogeneous photochemical oxidations and heterogeneous aqueous-phase, (and possibly particulate solid phase) oxidation processes take part. Emitted NO is oxidized to nitrous acid, HNO_2, and nitric acid, HNO_3, over homogeneous photochemical and chemical pathways in the gas phase.

The general picture for acid and basic components entering rain is summarized schematically in Figure 2.

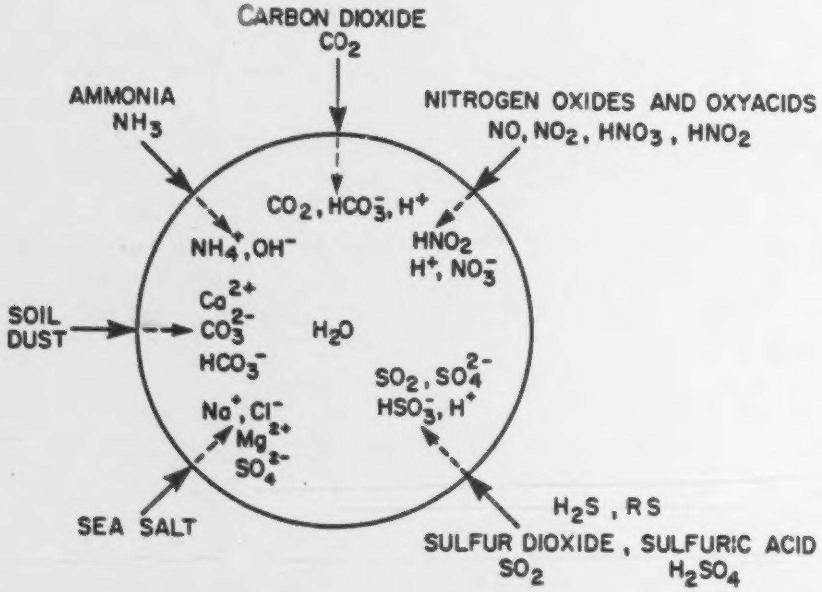
CARBON DIOXIDE
CO2
AMMONIA
NH3
NITROGEN OXIDES AND OXYACIDS
NO, NO2, HNO3, HNO2
CO2, HCO3-, H+
NH4+, OH-
HNO2
H+, NO3-
SOIL
DUST
Ca2+
CO3 2-
HCO3-
H2O
SO2, SO4 2-
HSO3-, H+
Na+, Cl-
Mg2+
SO4 2-
H2S, RS
SEA SALT
SULFUR DIOXIDE, SULFURIC ACID
SO2
H2SO4

Fig. 2. Source and Chemical Components Known to Take Part in Rain Acid-Base Chemistry.

Acidity and Base Neutralizing Capacity

The commonly-used definitions of acidity and alkalinity in water chemistry are based on the choice for a reference level for CO_2 aqueous solutions resulting from equilibrium between water and CO_2 at the partial pressure (fugacity) of the atmosphere. A temperature of interest is specified, thus fixing the pH, which depends on two acidity constants of $CO_2(aq)$ and Henry's law constant for CO_2. At an atmospheric CO_2 concentration of 335 ppmv (molecules of CO_2 per million molecules of air), the reference pH is 5.65. Solutions of pH > 5.65 and at equilibrium with the atmosphere have acid neutralizing capacity with respect to the reference level. This capacity factor is defined as the alkalinity. Solutions at pH < 5.65 at equilibrium with the atmosphere have base neutralizing capacity with respect to the same reference level. This capacity factor is referred to as "mineral acidity"; it results from the presence of acids stronger than CO_2 in water. The strong acids (HCl, HNO_3, H_2SO_4) are, by definition, stronger than CO_2. Chemical compositions in Table 1 and Figure 1 show that at the locations involved base neutralizing capacity of rain with respect to the CO_2 reference level, $[BNC]_{CO_2}$, is attributable entirely to the strong acids H_2SO_4 and HNO_3. The precipitation-weighted mean Pasadena rain (Table 1) was formed (per liter of rain) from 18 µmol H_2SO_4 (deducting the SO_4^{2-} contributed by seawater), 31 µmol HNO_3, 21 µmol NH_3 and 3.3 µmol $CaCO_3$. The value of $[BNC]_{CO_2}$ for rain with only these components is $[BNC]_{CO_2} = 2[H_2SO_4]_o + [HNO_3]_o - 2[CaCO_3]_o - [NH_3]_o$ and is 39 µeqℓ$^{-1}$. At Pasadena, the potential acidity or input acidity was 67 µeq $^{-1}$. Component bases NH_3 and $CaCO_3$ neutralized 42% of the input acidity. At Hubbard Brooks, approximately 30% of input acidity was neutralized, and at Söängen, approximately 45%.

The proton balance for rain with HNO_3, H_2SO_4 and HCl as the net acid components and with $CaCO_3$ and NH_4 as the only net basic components is $[H^+] + 2[Ca^{2+}] + [NH_4^+] = 2[SO_4^{2-}] + [NO_3^-] + [Cl^-] + [HCO_3^-] + 2[CO_3^{2-}] + [OH^-]$ and $[BNC]_{CO_2}$ in terms of solution species is $[BNC]_{CO_2} = [H^+] - [HCO_3^-] - 2[CO_3^{2-}] - [NH_3] - [OH^-]$. At pH > 5.65, $[BNC]_{CO_2} < 0$, or ALK $= -[BNC]_{CO_2}$. For rain at equilibrium with atmospheric CO_2 a knowledge of $[BNC]_{CO_2}$, the equilibrium constants for CO_2 solubility, CO_2 and HCO_3^- acidity and water ionization, plus constants for NH_3 solubility and NH_4^+ acidity, is sufficient to find $[H^+]$ or $\{H^+\}$. (If other acid-base gases, e.g., SO_2, HNO_2, NO_2, etc. are involved, their equilibria enter into the calculation via the proton balance.)

$[BNC]_{CO_2}$ can be obtained experimentally by titration to the CO_2 reference pH, or calculated for known or assumed input components.

Alkaline rain existed previously at locations now acidic and exists today in regions with strong sources of alkaline soil dust and ammonia in excess of natural sources of SO_2, H_2S, organic sulfur and NO_x or of natural sources plus anthropogenic sources. The U.S. NADP network shows extensive regions of Western North America with rain of pH > 5.5, unlike the Eastern U.S. and Canada, and unlike Northern Europe. Using rain analyses of Junge and Werbey for the Western U.S. in 1955-56 is is possible to estimate pH values by application of the charge-balance, CO_2-equilibrium relationships. The pH values obtained are considerably higher than those observed today in the Northeast United States or calculated for 1955-56 (11) from charge balances. Geographical relation to both acid and basic emissions and the transport-transportation times from source locations are recognized generally to be among the factors governing pH of rain.

Alternative Proton Reference Levels

It should be kept in mind that the *reference level* chosen for defining a neutralizing capacity is an arbitrary datum taken for convenience (analytical or computational), and may not necessarily have *direct* environmental significance without further interpretation. Chemical speciation, i.e., pH, metal ion, ligand and complexes in rain and in aquatic systems depends on *absolute* input concentrations or acid-base components and redox components. The reference level has no intrinsic significance for describing changes in H^+ availability and acidity. The concept of a proper *background* level for neutralizing capacity or proton activity should be distinguished from that of a reference level. For example, if rain at a location has been characterized at an earlier time by, say pH 7.5 and ALK = 100 $\mu eq \ell^{-1}$, and at a later time by pH 4.3 and $[BNC]_{CO_2} = 50$, it is clear that the overall *change* in the acidity-alkalinity balance is $\Delta[BNC]_{CO_2} = +150\ \mu eq \ell^{-1}$. Total acid (proton) input is $\Sigma\Delta[BNC]$ and can be compared with changes in emissions or changes in resultant $[BNC]_{CO_2}$ of aquatic systems (waters, sediments, soils).

ACIDITY AND OXIDATION (pH AND pε)

Proton transfer and electron transfer are analogous notions. The pH indicates activity of aqueous protons. A solution of low pH has relatively strong proton donating tendency; one of high pH has relatively strong proton accepting tendencies. Electron transfers formally describe an oxidation-reduction process. For example, the half-reactions for peroxide reduction

$$H_2O_2(aq) + 2H^+ + 2e = 2H_2O$$

and SO_2 oxidation

$$SO_2(aq) + 2H_2O = SO_4^{2-} + 4H^+ + 2e$$

combine to yield the overall reaction of $SO_2(aq)$ with H_2O_2:

$$H_2O_2 + SO_2 = SO_4^{2-} + 2H^+$$

generating increased H^+ and increased $[BNC]_{CO_2}$. Figure 3 summarizes the energetics of proton transfer reactions (part (a)) and electron transfer reactions (part (b)) in terms of the standard equilibrium constant for proton donation, K_a, and the standard equilibrium constant for unit electron acceptance, K_e, which is simply a measure of the free energy per electron transferred. For H_2O_2 reduction to H_2O, log K_e is 30; for SO_2

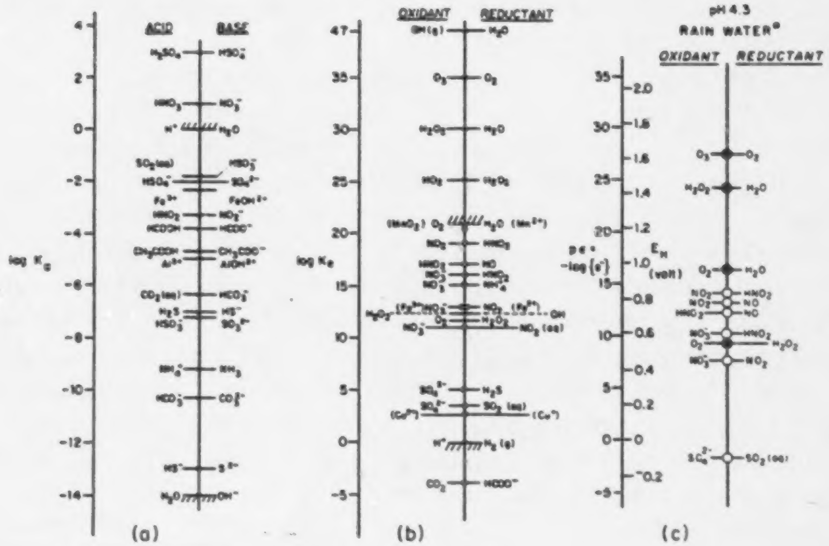

Fig. 3. Energetic levels for (a) proton-transfer ($HA = A^- + H^+$, K_a) and (b) electron-transfer ($OX + e = Red$, K_e) reactions. Part (c) shows non-equilibrium pε values estimated for rain at Pasadena (13).

oxidation to H_2SO_4, log K_e^{-1} is -3; for SO_2 oxidation by H_2O_2, (two electrons) log K = 54, which corresponds to the standard potential difference of 1.6 volts. Figures 3(a) and 3(b) emphasize a useful analogy between acid-base and oxidant-reductant reactions. The analog of $pH = -\log \{H^+\}$ is $p\varepsilon = -\log \{e^-\}$. Systems of low $p\varepsilon$ are strong electron donating (reducing) systems; systems of high $p\varepsilon$ are strong electron accepting (oxidizing) systems. As $pH = pK_a + \log$ (base/acid), so $p\varepsilon = p\varepsilon^o + \log$ (oxidant/reductant) for each half-reaction system. At complete equilibrium, the final pH and $p\varepsilon$ would give the respective acid/base and oxidant/reductant compositions for all pairs.

In Figure 3(a), acids higher on the scale can transfer protons to the bases lower on the scale. In Figure 3(b), higher oxidants and lower bases have a similar relationship. For acids, this leads, e.g., to the concepts of $[BNC]_{CO_2}$, counting all acids and bases in rain is: $\sum$[equivalent acids, $pK_a < 6.4$] - $\sum$[equivalent bases, $pK_a > 6.4$]. For TOTH total rain acidity one could choose: $\sum$[equivalent acids, $pK_a < pK_w$] - $[OH^-]$.

Any acidity capacity implies a defined redox reference level as well. Thus NH_3 oxidation to HNO_3, H_2SO_4 reduction to H_2S, CH_3COOH oxidation to CO_2, etc. change acidity capacity by creating or destroying acidity. This simply says that the equilibrium state requires specification of both pH and $p\varepsilon$.

An oxidation capacity for rain can be readily identified in terms of Figure 3(b). Any electron reference level can be selected, say $K_{e,ref.}$. Then, the oxidation capacity, [OX], is $\sum$[equivalent oxidants, $K_e > K_{e,ref}$] - [equivalent reductants, $K_e < K_{e,ref}$]. If the $SO_4^{2-}/SO_2(aq)$ electron level is chosen, only Cu^+, H_2, and $HCOO^-$, of the reductants depicted would enter into the oxidation capacity. Not all half-reactions included are compatible in an equilibrium solution. In practice, as for BNC, only a limited number of species may be influential. Oxidation capacity depends on pH, because redox species, e.g., SO_2, HSO_3^-, SO_3^{2-} are related by proton equilibria.

Figure 3(c) is an example of calculated apparent $p\varepsilon$ values for rain at Pasadena (13), based on measured aqueous concentrations or gas-phase concentrations of O_3, H_2O_2, O_2, SO_2, HNO_2, NO_3^-, NO and NO_2 in local rain. Ozone and hydrogen peroxide would be unstable in the rain, being much stronger oxidants than O_2. NO_2, NO, and NO_3^- are out of equilibrium, because of slow two-phase kinetics. From the concentrations of these species an apparent oxidation capacity, [OX] can be calculated with respect to an SO_4^{2-}/SO_2 reference level, 1.47×10^{-3} eqℓ$^{-1}$. This stems 85% from $O_2(aq)$ and ∿15% from NO_3^-. The median levels of the known powerful and kinetically active oxidants, O_3 and H_2O_2, are less than equivalent to the SO_2 reductant at air-rain equilibrium for pH 4.3. However, true levels of H_2O_2 are not yet well known. The equilibrium scavenging level could be as high as 10^{-5}M, or 2×10^{-5} eqℓ$^{-1}$ of aqueous oxidant for an initial air concentrations of 1 ppbv, based on Henry's law constant for H_2O_2 at 25°C.

TOTAL ATMOSPHERIC ACIDITY

Acid-base and redox processes may take place in the gas phase, in aerosol phases and in cloud and fog. The acidity of rain is a reflection of the components and species entering into the various atmospheric phases, e.g., HNO_3, H_2SO_4, H_2S, SO_2, NH_3, $(CH_3)S$, CO_2, etc. It might be useful to define the total (over several phases) acidity of a volume of atmosphere, by relating stoichiometrically actual acid-base components and species to the acid and base species that could donate or accept protons with respect to some reference level. For example, H_2SO_4 releases two protons, upon oxidation NO_2 releases one proton, etc. (An extension to total oxidation capacity is evident.) As for acidity of rain, alternative pH levels and redox states can be chosen, e.g. $[BNC]_{CO_2}$ and most-oxidized, TOTH and partially-oxidized, etc. Assuming such a set of levels,

$$\begin{Bmatrix}\text{Total}\\ \text{Acidity}\end{Bmatrix} = \begin{Bmatrix}\text{Aerosol}\\ \text{Acidity}\end{Bmatrix} + \begin{Bmatrix}\text{Gas Phase}\\ \text{Acidity}\end{Bmatrix} + \begin{Bmatrix}\text{Cloud}\\ \text{Acidity}\end{Bmatrix} + \ldots$$

In terms of known gas concentrations p_i, water concentrations $[X_i]$ aerosol-phase concentrations (X_i), liquid water content L and a set of stoichiometric acid (>0) or base (<0) coefficients b_i, g_i and a_i, which depend on H^+ and e^- reference levels chosen,

$$\begin{Bmatrix}\text{Total}\\ \text{Acidity}\end{Bmatrix} = \frac{1}{RT}\sum b_i p_i + L\sum g_i[X_i] + \sum a_i(X_i)$$

where the acidity is referred to unit volume of air. For certain purposes, e.g., potential acidity, the water phase can be excluded. Total acidity represents a way of defining potential acidification by rain, fallout, etc., and a basis for constructing an acidity balance in terms of a conserved property, subject to precise definition of H^+ and redox reference levels. Different levels are appropriate, for different environmental situations, e.g., short-term vs long-term or oxidized vs reduced conditions.

PRODUCTION OF RAIN ACIDITY

Availability of H^+ and base neutralizing capacity of rain result from: (i) net transfer or scavenging of pre-existing acidic and basic components and species from aerosols and gaseous species in air,and (ii) from generation of acids in cloud and rain. Mechanisms and rates of the scavenging processes determine the initial composition of cloud and rain and thus set the aqueous chemical conditions (pH, metals, buffers, ligands, aqueous SO_2 and NO_x, and oxidants such as O_3 and H_2O_2 for heterogeneous SO_2 oxidation. Gaseous and aerosol species scavenged by atmospheric water are formed by homogeneous photochemical reactions and multiphase gas-to-particle conversion processes. Emitted reduced sulfur compounds, H_2S, RS, and SO_2 are partially oxidized in the troposphere to H_2SO_4 via photochemical, free-radical pathways involving O_3, OH, H_2O_2, HO_2, RO_2, and $O(^3P)$. Emitted NO and NO_2 are partially oxidized to HNO_2 and HNO_3 by similar photochemical pathways (where NO and NO_2 themselves play important roles in O_3 formation) with OH, O_3, RO, and H_2O_2 as reactants and products.

Unoxidized SO_2 in the air dissolves in clouds or aerosol water where O_2, O_3, or H_2O_2 oxidation gives H_2SO_4. Unoxidized SO_2 also is removed from the trophosphere by dry deposition. Reaction of H_2SO_4 with NH_3 leads to ammonium sulfate aerosols, e.g., NH_4HSO_4 or $(NH_4)_2SO_4$. The aerosols may be scavenged during cloud formation (nucleation scavenging) and by aerosol-droplet collisions in the clouds (diffusion). Both SO_2(gas) and $(H_2SO_4)_x(NH_3)_y$ (aerosol) are scavenged by raindrops. Efficiency of rain drop aerosol scavenging depends strongly upon the aerosol size distribution (smaller particles are poorly captured). SO_2 scavenging by cloud and rain can be treated as a reversible gas-aqueous distribution since mass transfer is generally rapid. Dry deposition is a slow process for the submicron aerosol fraction, which dominates H_2SO_4.

Nitric acid reacts rapidly with ammonia to produce NH_4NO_3 aerosol, which is scavenged by clouds and rain or removed by dry deposition. NH_4NO_3 has a relatively high vapor pressure for $NH_4NO_3 \rightarrow NH_3 + HNO_3$, and the variation with temperature is great. This may have implications for scavenging efficiency. Gas phase HNO_3 can be scavenged by cloud and rain (as can HNO_2) or be absorbed at the earth's surface. At higher relative humidity HNO_3 will tend to condense on aerosol particles.

A potential liquid water sink for NO and NO_2 is reaction via the two-phase equilibria

$$2NO_2(g) + H_2O(\ell) \rightleftharpoons H^+ + NO_3^- + HNO_2(aq)$$

$$NO(g) + NO_2(g) + H_2O(\ell) \rightleftharpoons 2HNO_2(aq)$$

However, the overall two-phase rates are not rapid, showing characteristic times much longer than typical cloud life or rainfall time (9). Possibilities of other, more rapid two-phase mechanisms involving NO and NO_2 need exploration (e.g., aerosols as the sites, or catalysis in cloud water). Other products of photochemical oxidations of NO and NO_2 (N_2O_5, organic nitrates, peroxynitric acid) are either dry-deposited or taken up in aerosols or precipitation. N_2O_5 yields nitric acid directly in an aqueous phase.

Factors which should govern rain acidity from SO_2 and H_2SO_4 components include: (a) concentrations of SO_2 and sulfuric acid aerosol in the air and their vertical distributions; (b) aerosol particle size distributions and associated chemical distributions of H_2SO_4 and $(H_2SO_4)_x(NH_3)_y$ species; (c) vertical distributions of O_3 and H_2O_2 concentrations in the air, with their possible roles in aqueous phase H_2SO_4 formation from SO_2; (d) initial air concentration of neutralizing bases, e.g., NH_3 and $CaCO_3$, which set initial pH values together with H_2SO_4 and HNO_3; (e) microphysical characteristics (sizes and numbers of cloud droplets as well as other characteristics, e.g., evaporation); (f) rain drop size distributions; (g) rate of precipitation (dilution effect).

For acidification by the NO- and NO_2-derived acids, HNO_3, HNO_2 (and N_2O_5 intermediate) governing factors are roughly similar. The tropospheric concentrations of gas-phase HNO_3, N_2O_5, and HNO_2 and of species associated with the aerosol HNO_3 component are of central importance. Size distributions (submicron vs above) and temperature effects on NH_4NO_3 volatility are of interest. It is evident that the acidic species in the air available to be scavenged by clouds and rain at a particular location depend on source magnitudes of S and N upon compounds, geography of sources, air trajectories, regional photochemical setting (and thus upon all relevant emissions, e.g., hydrocarbons, SO_2, NO, CO, etc., and upon season of the year) in addition to scavenging factors. For a distribution of concentrations of SO_2 and H_2SO_4 in aerosol, theoretical considerations suggest that cloud nucleation scavenging, interception and impaction of giant aerosols, and SO_2 cloud scavenging followed by oxidation (O_3, H_2O_2) in that order are dominant acidification mechanisms leading to H_2SO_4 in rain (3). For a given distribution of HNO_3(g) and HNO_3(aerosol)concentrations it appears that nucleation scavenging in clouds should play an important role, depending on the size distributions, particle properties, and temperature. If gaseous HNO_3 concentrations in air are comparable to those for aerosol NO_3^-, gas scavenging in cloud by rain will be important. HNO_3 scavenging can be close to 100% because of the large (10^6M atm^{-1}) Henry's constant for HNO_3/H_2O. If larger aerosol sizes are important for HNO_3, impaction and interception by raindrops can contribute significantly to acidification as well. Particle size distribution data are not abundant for nitrates. It is difficult to draw conclusions about scavenging of HNO_3 in comparison to that for sulfur acids.

Concentrations From Scavenging

For aerosol scavenging of component X the resulting cloud or rain concentrations can be related by $[X] = (X)\epsilon f/L$ (8) in which [X] is aqueous concentrations, (X) is aerosol concentration (e.g., mole per volume of space), ϵ is efficiency, f accounts net cummulative evaporation or dilution, and L is the liquid water content per volume of space. For equilibrium gas scavenging aqueous concentration is given by (scavenged component being conserved per unit volume of space): $[X_i] = (P_{i,o}K_H\alpha_o^{-1})/(1+LRTK_H\alpha_o^{-1})$ in which $P_{i,o}$ is initial gas partial pressure, K_H is Henry's law constant (M atm^{-1}) and α_o is the fraction of undissociated dissolved gas in solution, a function of pH and acidity constants, hence T. For a "completely" scavenged gas, the concentration is just $[X_i] = P_{i,o}/LRT$. At the pH of acid rain HNO_3 is completely scavenged, NH_3 is scavenged well in excess of 90%, and SO_2 is scavenged to just a few percent. H_2O_2 is completely scavenged, independent of pH. O_3 is scavenged to very small extent.

Rain chemistry data at Pasadena (Table 2, Figure 1) suggest that SO_4^{2-} and NO_3^- aerosols contribute substantially to observed rain concentrations, perhaps greater than 50%, for each. At least 12% of excess sulfate at Pasadena can be accounted for by SO_2 scavenging and subsequent oxidation; the corresponding value at Riverside is in excess of 24% (12). With respect to total emissions, for which the equivalent potential acid ratio of NO_x to SO_2 (1975-76) was ∿ 2.3, HNO_3 is less efficiently scavenged in the L. A. Basin than H_2SO_4 ($[NO_3^-]/1[SO_4^{2-}]$ ∿ 0.8 in the mean rain). This may reflect the fact that dry deposition and advection are the major output terms; it might, in part, reflect relative scavenging of the N and S components.

Importance of Heterogeneous Oxidations

The residence time of sulfur in the troposphere is believed to be on the order of one week or so. Photochemical reactions yield characteristic $SO_2 \rightarrow H_2SO_4$ conversion times on the order of a week, but not under winter conditions. Known homogeneous photochemical mechanisms for sulfur seem unable to account for observed year-round levels of SO_4^{2-} in rainfall. Oxidations in cloud and fog of absorbed SO_2 by H_2O_2 and O_3 appear able to account for very high rates where photochemical paths cannot (15). Figure 3(b) shows that MnO_2 and Fe^{3+} are able to oxidize SO_2 in acid solutions. In Los Angeles high sulfuric acid formation rates appear to be correlated with high relative humidity. A kinetically-attractive alternative path to photochemical oxidation of NO_x has not been delineated; catalyzed oxidations in aqueous aerosol phases or cloud have been mentioned as possibilities.

Interactions and Feedback in the Sulfur-Nitrogen System

The key role of the OH radical (and also H_2O_2)in the photochemical oxidation mechanisms of both NO_2 and SO_2 and the faster rate for NO_2 by a factor of ∿10 has suggested the possibility that the rate of homogeneous oxidation of SO_2 might be slowed by emissions of NO_2 (16). Rodhe, Crutzen and Vanderpol have advanced a simple photochemical, transport model which indicates that long-range transport of HNO_3 can be less-pronounced than for H_2SO_4. In the model NO_2 emissions delay and decrease the oxidation of SO_2 to H_2SO_4 because of competition for OH. They advance the tentative conclusion that a linear dependence of atmosphere concentrations on emission rates may not be assumed because of non-linear photochemical mechanism interactions.

In heterogeneous aqueous phase conversion of scavenged SO_2 (SO_2(aq) and HSO_3^- species) certain rate laws, e.g., those with O_2 or O_3 as oxidant, predict slower conversions upon acidification, in part because total dissolved $[SO_2 + HSO_3^-]$ decreases with lowering of pH. Rapid HNO_3 scavenging could thus lead to inhibition of the SO_2 oxidation rate. Interestingly, the laboratory rate law for oxidation of $SO_2 + HSO_3^-$ by $H_2O_2(aq)$ does not have this negative feedback at lower pH. Interactions in the gas phase and aqueous phase oxidations (aerosol, cloud, fog) of SO_2 and NO_2 are deserving of greater attention under chemical conditions actually encountered in the atmosphere.

Background Acidities and pH

The global background emissions of H_2S, RS, SO_2, and NO_x might provide a rough estimate of background inputs $[BNC]_{CO_2}$ and pH to rain (although the idea of a "global" background is probably untenable, with S residence times as short as a week or less). If we take the following estimated input fluxes for sulfur and odd nitrogen based on the SCOPE report (18), $F_s = 30$ Tg S y^{-1} and $F_{NO_x} = 15$ Tg N y^{-1}, the equivalent acid flux is 3 T eq y^{-1}. Perhaps two-thirds enters the rain. Assume all of this becomes oxidized. Dividing by the global annual rainfall, 4.5×10^{17} ℓ y^{-1} gives a $[BNC]_{CO_2}$ of 4 μeqℓ$^{-1}$ and pH of 5.4 (by solving the proton balance equation for 25°C). If a background ammonia flux is taken, say 30 Tg N y^{-1} (18), then, since NH_3 is extensively scavenged by rain, $[NH_4^+] \sim 5\times10^{-6}$ eqℓ$^{-1}$, $[BNC]_{CO_2} \sim -$[illegible]$\times10^{-6}$ eq $^{-1}$ and pH ∼ 5.8. More base, e.g., sea salt or alkaline dust would further raise the pH; more acid aerosol or gas would lower it. The buffer density, $d[BNC]_{CO_2}/d$ pH is small in this pH region. A background pH is difficult to characterize. At remote marine locations with low inputs of all acids and bases, variations in the amount of slightly alkaline marine aerosol scavenged, variations in ammonia concentrations, and small variations in fluxes of the acids could easily cause pH variations between, say 5.3 and 5.9.

If, for a remote marine location, (HNO_3) is 0.5 μg/m^3, (H_2SO_4) is 1.1 μg/m^3, p_{SO_2} is 10^{-10} atm and p_{NH_3} is 10^{-10} atm, the pH of cloud can be computed by solving the proton balance equation with p_{CO_2}, $p_{NH_3,0}$ (the initial value) and $p_{SO_2,0}$ as constants and assuming a cloud liquid water content of $L = 10^{-6}$ (vol water/vol space). Alternatively, a titration curve can be constructed showing added net non-volatile acids and bases (H_2SO_4, HNO_3, $CaCO_3$), or $[BNC]^*_{CO_2}$, vs pH. Response to variations of total input BNC can then be examined directly. Figure 4 shows a result for assumed constraints (25°C). A value of $f\varepsilon \sim 1$ has been taken for aerosol scavenging. For the

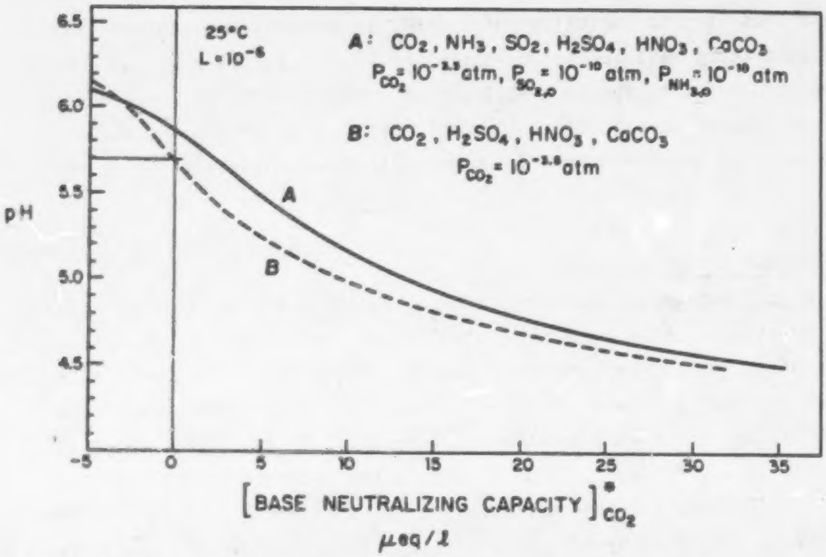

Fig. 4. Titration Curve for Two-phase Aqueous-Gas Systems with Indicated Components. $[BNC]^*_{CO_2}$ is the total added equivalent concentration of non-volatile acids or bases. (The titrations combine mass-conservation in two phases with open-phase equilibria.)

scavenged acid concentrations chosen pH = 4.5 (curve A). In the absence of NH_3 and SO_2 the pH (curve B) the pH would be ∿ 0.1 unit lower. The pH of rain would depend on the actual values of fε locally. At smaller net acid, dissolved NH_3 provides greater buffering. Lower temperatures would raise curve A and lower curve B. Around $[BNC]^*_{CO_2}$ ∿ 0, NH_3, alkaline dust, and small acid inputs can alter a background pH significantly. (The alkalinity contribution from sea salt is ∿ 0.2 µeqℓ$^{-1}$ per mg/ℓ of Na^+.) Similar considerations have recently been put forward in an elegant analysis by Charlson and Rodhe (2).

Present Day Global Acid Fluxes

The SCOPE (18) estimates place man-made NO_x emissions at around 20 Tg N y^{-1}, and man-made SO_2 emissions at around 70 Tg S y^{-1}. A rough estimate of $\Delta[BNC]^*_{CO_2}$ in rain would be about 9 µeqℓ$^{-1}$ on a "global" basis. If the inputs were spread uniformly, then ΔpH would be about 0.5 to 1.0 "globally". Local and regional scales are the most affected. It is not unexpected to find pH values in the range 5 to 4 and even below in rain found downwind from local and regional NO_x and SO_2 emissions which together yield equivalent acid input loadings in excess of regional alkaline inputs by ∿ $2x10^2$ to ∿ $2x10^3$ eq H^+ ha^{-1} y^{-1}. Global potential H^+ loadings (∿10^2 eq $ha^{-1}y^{-1}$) and Eastern N. American loadings (∿ 10^3) are in this range. The physical and chemical details of the acid-base and redox "titrations" are highly complex in time and space and will depend, in addition to the matrix of emissions, on climatologic, meteorologic, photochemical, and geologic details of regions. The global and regional emission loadings assure acid rain; experience confirms this in many regions of the world. A general picture of the information required to predict where, when and with what intensity is now almost at hand.

SOME QUESTIONS AND PROBLEMS

It seems important to ask whether photochemical mechanisms can predict HNO_3 inputs to rain spatially and temporally. If not, what processes can account for observed NO_3^- levels in rain? The suggested non-linear character of emissions vs. atmospheric concentrations of HNO_3 and H_2SO_4 invites further examination. Control strategy questions may hinge on this aspect of atmospheric acidity. Better understanding of local scavenging of H_2SO_4- and HNO_3- bearing species by cloud and rain requires detailed information on particle size distributions of HNO_3 and H_2SO_4 aerosol acidities and on the HNO_3(g)/HNO_3(aerosol) distribution. Key questions related to heterogeneous SO_2 oxidations (cloud, aerosol) concern chemical speciation factors in the solution for reductant, oxidants, and catalysts.

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CONCERNING "ACID RAIN" LEGISLATION

FOR HEARINGS OF SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

May 25, 1982

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STATEMENT OF VOLKER A. MOHNEN, Ph.D.

My name is Volker A. Mohnen. I hold a Ph.D. degree in physics, with a minor in meteorology and astrophysics, from the University of Munich. I am currently the Director of the Atmospheric Sciences Research Center and a Research Professor in the Department of Atmospheric Sciences at the State University of New York at Albany. I am actively involved in research in the fields of air pollution, air chemistry and related subjects such as "acid rain," and am the author of more than 135 publications and reports dealing with those subjects. A copy of my curriculum vitae is submitted herewith for the record.

This statement addresses the pending bills that would require reductions in sulfur dioxide (SO_2) emissions in the eastern United States in an attempt to protect the environment from adverse effects of the deposition of acidic materials, often referred to as "acid rain." I have testified previously on this subject. On November 5, 1981, I submitted a statement to this Committee on S. 1706. That statement covers in more detail some of the same points made in this statement.

1. Introduction

Acidic deposition may be wet or dry. Wet acidic deposition is caused by the oxidation of SO_2 and oxides of nitrogen (NO_x) into sulfates (including sulfuric acid) and nitrates (including nitric acid) and their subsequent removal from the atmosphere and delivery to the ground by precipitation (rain, snow, dew, etc.). Dry deposition includes the dry fallout of SO_2 and NO_x gases from the atmosphere to the ground, where they are converted to sulfates and nitrates upon sorption by vegetation, water surfaces and soils. It also includes the dry fallout of fine sulfate particles which are formed in the atmosphere from SO_2 and then settle to the ground and add to the overall sulfate burden of soils and watersheds.

Certain limited areas, particularly in the northeastern United States (e.g., the Adirondacks), have been identified as suffering adverse effects from acidic deposition. The goal of the pending bills is to protect such sensitive areas from degradation caused by acidic deposition, and they aim to do this by requiring major reductions in emissions of the precursor gases, particularly SO_2. For example, some of these bills would require a reduction in SO_2 emissions in the 31 States east of the Mississippi River by 50%, or 10 million tons, over the next 10 years.

Since I am not an expert on the ecological effects of acidic deposition, I am not in a position to judge how big a reduction in the deposition of acidic materials is needed to protect sensitive areas from further degradation, or over what period of time such reduction in deposition should be achieved before irreparable damage in those areas occurs. My expertise is in the area of atmospheric chemistry and the mechanisms and processes that lead to acidic deposition. Hence, this statement will focus on the strategy adopted in the pending bills to control acidic deposition — namely, requiring certain major reductions in emissions, particularly of SO_2.

The pending legislation seems to assume that the mandated reduction in SO_2 emissions will produce a significant decrease in acidic deposition in the sensitive areas. More specifically, since the burden of the required reduction in SO_2 emissions will fall most heavily on the States with relatively high emissions -- such as Ohio, Indiana and other midwestern States -- a major, although unstated, theory of the bills seems to be that such reductions in SO_2 emissions from sources in those midwestern States will significantly decrease acidic deposition in the sensitive areas of the Northeast.

The hypothesis underlying the strategy of these bills is not supported by the scientific research that has been conducted on the processes leading to acidic deposition. At present, our understanding of those processes is too limited to make it possible to predict with any degree of accuracy what changes, if any, in wet and dry acidic deposition in the environmentally sensitive areas would result from the emissions reduction that would be required by these bills. Certainly, no source-receptor relationship can be established that could be used for regulatory decision-making. What limited research has been done to date indicates that the reduction in SO_2 emissions called for by the pending legislation would most likely not result in an equivalent reduction in acidic deposition in the sensitive areas and might result in no measurable decrease in wet deposition at all. This means that the control strategy adopted by these bills cannot be defended on the basis of science at this time.

Let me now try to explain the bases for these conclusions.

2. Research on Wet Deposition Indicates That There is No Linear Relationship Between Emissions in the Midwest and Wet Acidic Deposition in the Northeast.

Contrary to the assumption that changes in upwind emissions of SO_2 and NO_x will result in similar changes in acidic deposition downwind, research that has been done to date provides good evidence that there is no such linear relationship between emissions of those precursor gases and wet acidic deposition in the eastern United States. That evidence indicates that the occurrence and extent of such deposition appear to be governed by factors other than the magnitude of upwind emissions -- most importantly, the sheer volume of precipitation, as well as the presence and ratio of copollutants and other meteorological, air chemical and in-cloud chemical factors that are not well understood.

My colleagues and I at the Atmospheric Sciences Research Center have analyzed wet deposition of pollutant-related ions (hydrogen, sulfate, nitrate) at selected sites in the Northeast and Midwest and attempted to determine the origin of the air masses contributing to that deposition and to develop a regional pattern for such deposition. This peer-reviewed research has been reported (or accepted for publication) in several publications (Wilson et al., 1980; Wilson et al., 1982; Wilson and Mohnen, 1982) and was discussed at length in my statement of November 5, 1981, to this Committee (pp. 6-17). Our basic findings included the following:

We found that the amount of deposition of the pollutant-related ions does not appear to depend on the level of emissions in the regions over which the air mass has passed, but rather depends primarily on the volume of precipitation. For example, an analysis of the precipitation chemistry at Whiteface Mountain, New York (which is located in the Adirondack area said to be sensitive to acid rain), in relation to the direction of the air masses arriving there, showed the following: In 1978, air masses from the Midwest/Ohio Valley sector delivered 56% of the annual precipitation, 62% of the annual hydrogen (H^+) deposition, 64% of the annual sulfate ($SO_4^=$) deposition and 65% of the annual nitrate (NO_3^-) deposition, while air masses from the Canadian/Great Lakes sector (which has much lower emission levels) delivered 26% of the annual precipitation, 31% of the annual H^+ and $SO_4^=$ deposition and 28% of the annual NO_3^- deposition.*/ Thus, the wet deposition directional pattern followed closely the directional pattern in precipitation amount. In simple terms, since most of the precipitation was delivered by air masses from the Midwest/Ohio Valley sector, most of the wet ion deposition came with it. The results from other sites in the Northeast likewise show a clear linear relationship between precipitation volume and wet deposition of the pollutant-related ions regardless of where the air mass came from. These findings demonstrate that precipitation volume, more than any other factor, governs the amount of wet deposition of these ions.

If emission levels upwind were an important factor in determining the amount of wet ion deposition downwind, one would expect to see the significant differences in emissions between the Midwest/Ohio Valley and the Canadian/Great Lakes sectors reflected in the directional patterns for deposition at downwind sites. For example, since we found a substantial difference in the ratio of annual SO_2 emissions to annual NO_x emissions between the Midwest/Ohio Valley (10,900,000 tons/3,760,000 tons = 2.9) and the

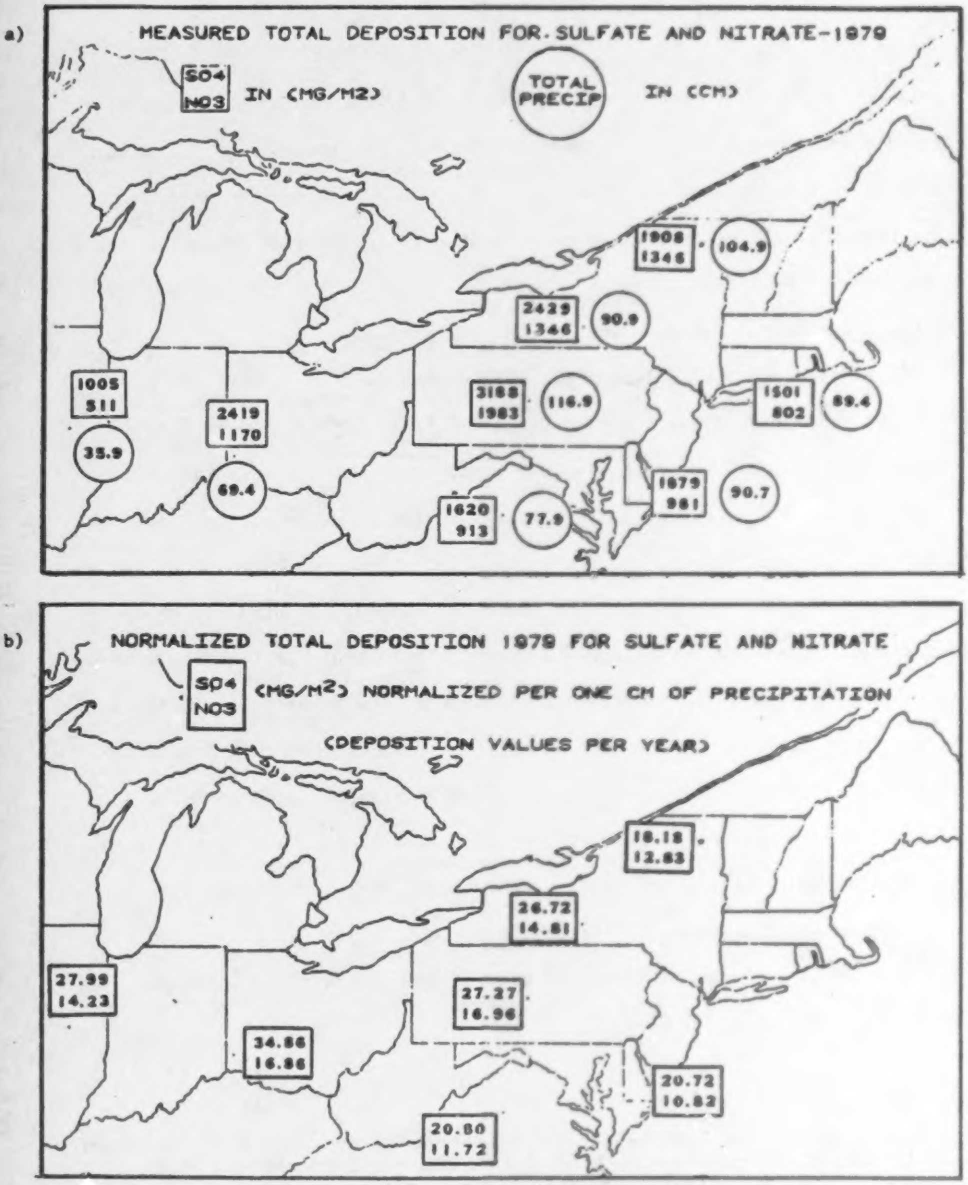
---

*/ The remaining, "Eastern" sector accounted for only five precipitation events and these five events resulted predominantly from wintertime snow storms. Because of the small number of events and the special meteorological situation, these events do not justify any emphasis. Air chemists now know that sulfate levels are significantly lower in the wintertime than in summer and that snow conditions are different from rain in that they are associated with a different (i.e., slower) rate of conversion of SO_2 into sulfates than occurs with rain.

Canadian sector (3,010,000 tons/157,000 tons = 19.2), one might expect to see this difference reflected in a similar difference in the $SO_4^=/NO_3^-$ deposition ratio at Whiteface Mountain between the air masses from the two sectors. The data presented above, however, show no such difference; they indicate that the ratio of $SO_4^=/NO_3^-$ deposition for the Midwest/Ohio Valley air masses is very similar to that for Canadian/Great Lakes air masses.

Moreover, in analyzing the 1979 deposition and precipitation data from the MAP3S site locations (Whiteface Mountain; Ithaca, NY; Penn State; Virginia; Lewes, DE; Oxford, OH; and Champaign, IL) -- shown in Figure 1a -- we normalized the annual deposition data for precipitation amount (i.e., per centimeter of precipitation). These annual normalized deposition data -- shown in Figure 1b -- show no significant west-to-east gradient in the wet deposition of sulfate and nitrate (a gradient that would be indicative of increased wet deposition downwind of major emissions areas in the Midwest). Rather, they show a surprisingly even distribution of these wet deposition ions throughout the northeastern part of the country, bounded by Whiteface Mountain and Champaign. Similarly, using the deposition data both from the MAP3S sites and from the additional sites in the NADP network and again normalizing per centimeter of precipitation, the results again show no significant west-to-east gradient in the wet deposition of $SO_4^=$ and NO_3^-, as shown in Figures 2 and 3.[*/]

[*/] The stations used for these figures did not include any in the southwest portion of the figures (i.e., the States of Missouri, Arkansas, Louisiana, Kentucky, Tennessee, Mississippi and Alabama), and hence the isopleths for that area may change as more stations are added. But this does not affect the basic conclusion regarding the lack of a significant west-to-east gradient from the Midwest to the Northeast.


a)
MEASURED TOTAL DEPOSITION FOR SULFATE AND NITRATE-1979
SO4
NO3
IN (MG/M2)
TOTAL PRECIP
IN (CM)
1908
1346
104.9
2429
1346
90.9
1005
511
35.9
2419
1170
69.4
3188
1983
116.9
1501
802
89.4
1879
981
90.7
1620
913
77.9
b)
NORMALIZED TOTAL DEPOSITION 1979 FOR SULFATE AND NITRATE
SO4
NO3
(MG/M2) NORMALIZED PER ONE CM OF PRECIPITATION
(DEPOSITION VALUES PER YEAR)
18.18
12.83
26.72
14.81
27.99
14.23
27.27
16.96
34.86
16.86
20.72
10.82
20.80
11.72

Figures 1a & 1b. a) Measured, and b) Normalized sulfate and nitrate deposition, 1979.

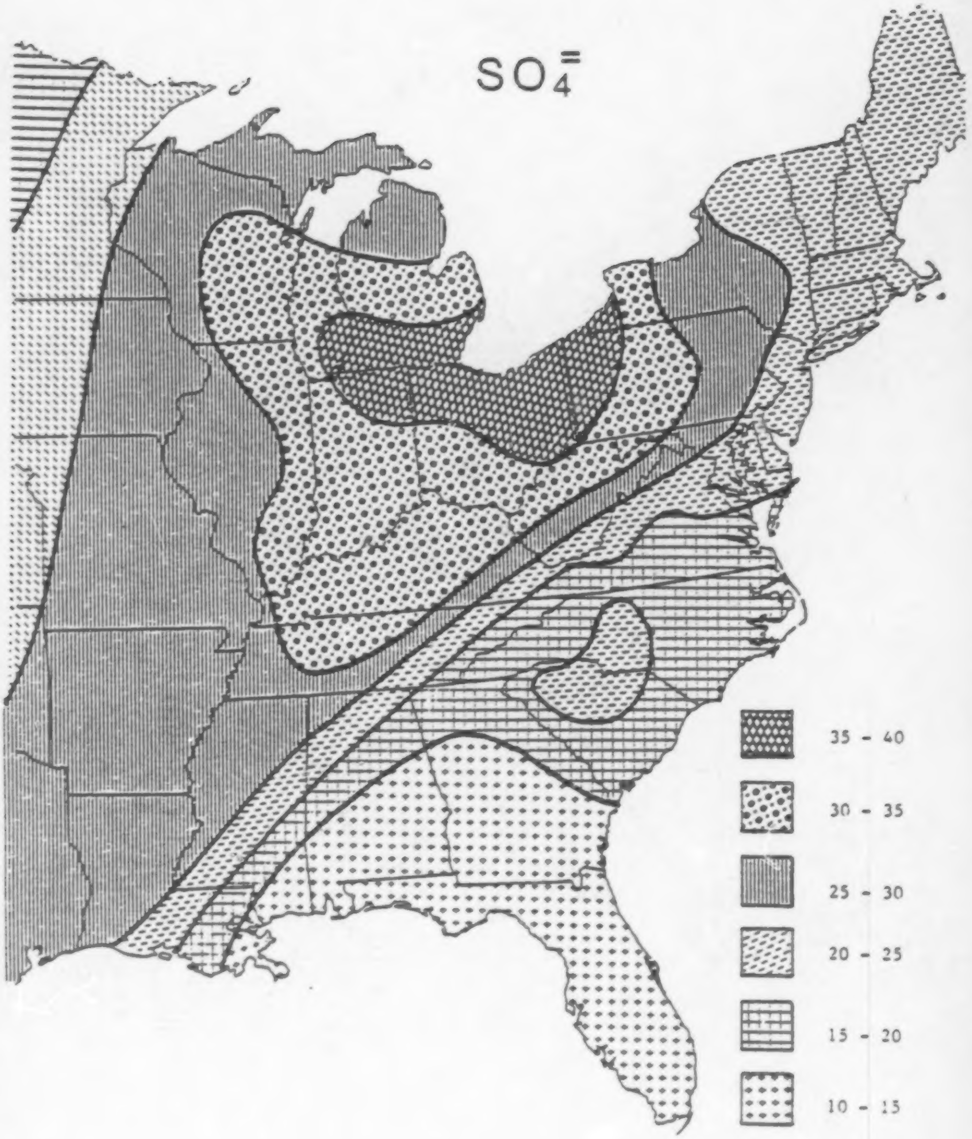

SO$_4^=$
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15

Figure 2. SO$_4^=$ deposition (mg/m^2) normalized per cm of precipitation for 1979.

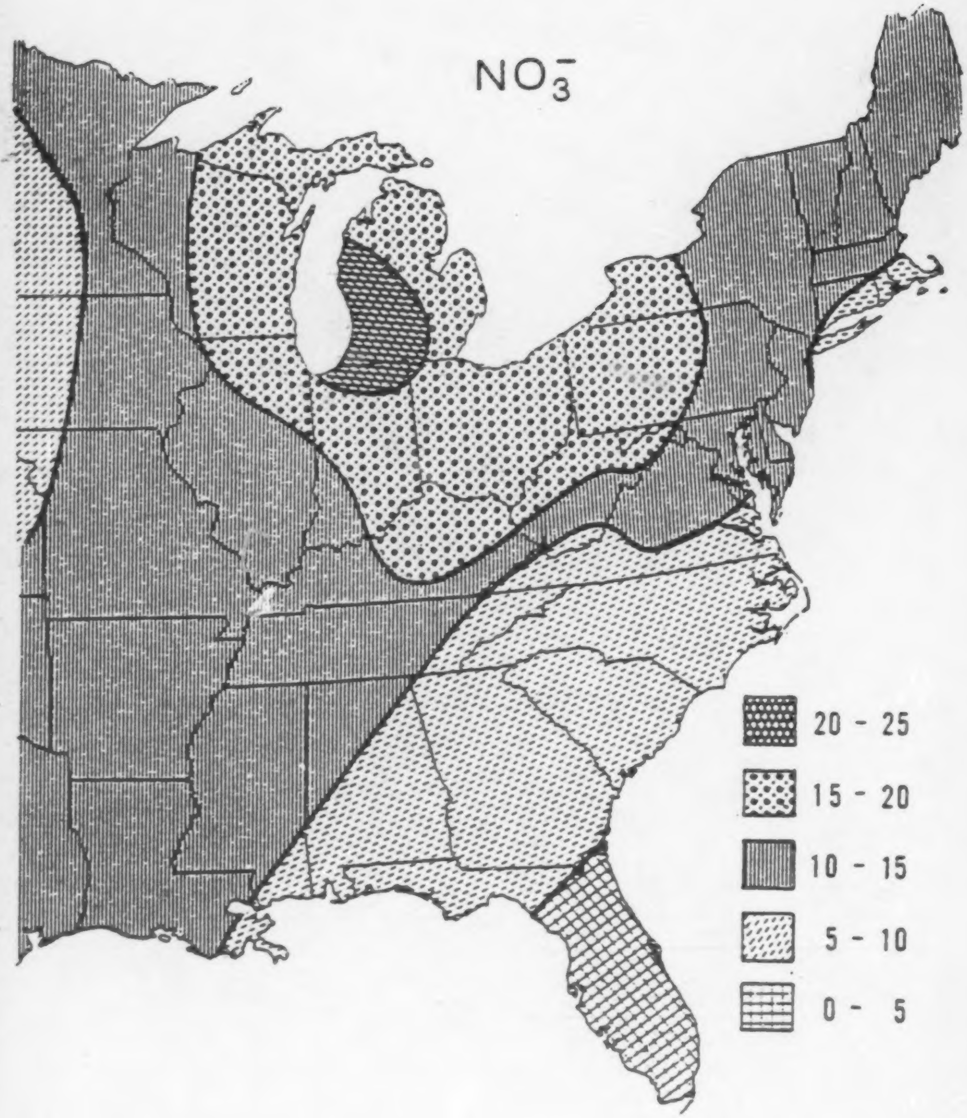

NO_3^-
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5

Figure 3. NO_3^- deposition (mg/m^2) normalized per cm of precipitation for 1979

This lack of a significant west-to-east gradient is further illustrated by an examination of the wet deposition data as measured from the following MAP3S stations for the summer (May-October) of 1978, during which period daily trajectory analysis showed predominantly southwesterly to westerly flow for precipitation-producing air masses arriving at Whiteface Mountain. Those data (given in milliequivalents) include the following:

	$SO_4^{=}/m^2$	NO_3^{-}/m^2	$SO_4^{=}/NO_3^{-}$ Ratio
Whiteface Mt.	29.13	10.78	2.7
Ithaca	37.14	13.52	2.7
Penn State	37.08	13.88	2.7
Virginia	30.95	10.86	2.8
Champaign	28.13	10.91	2.6

These results support the concept of a regional "superbowl" in the eastern industrialized United States -- i.e., a synoptic-scale airshed that results in acidic material being rather uniformly spread out in all directions over a very large region, rather than resulting in a significant west-to-east gradient. This indicates further that there is no linear relationship between emissions in the Midwest and wet acidic deposition downwind in the Northeast.

3. The Nonlinear Relationship Between Emissions and Deposition Can Be Explained by the Concept of a "Chemically Saturated Airshed" with Respect to SO_2 in the Eastern Industrialized United States, Which Means That a Reduction in SO_2 Emissions Would Not Yield an Equal Reduction, and Might Not Yield Any Reduction, in Acid Rain in that Region.

The above-mentioned experimental results showing a nonlinear relationship between emissions and wet deposition in the region characterized as the "superbowl" can be explained, in summary fashion, as follows: Of the primary pollutants, e.g., SO_2, emitted into the air, not all is converted to secondary products, e.g., sulfates and sulfuric acid, in the atmosphere. The rate of such conversion is determined by the availability of "oxidizing agents" -- e.g., certain radicals (OH, HO_2, H_2O_2, RO_2), ozone, "soot," etc. The availability of these agents, in turn, depends on the concentration and interaction of the primary copollutants (NO_x, reactive hydrocarbons and carbon monoxide, as well as SO_2), on the concentration of methane and ozone and on other meteorological and air chemical conditions -- e.g., humidity, temperature, solar radiation, ventilation (wind speed), photochemical reactivity of the air (which can be indicated by the ratio of reactive hydrocarbon to NO_x emissions), etc. These conditions vary with time at any given location, and they vary from area to area during the travel time of an air mass. Hence, the rate of conversion of SO_2 to sulfate and sulfuric acid varies (from a fraction of a percent up to about 10% per hour for gas phase reactions and up to 100% per hour for liquid phase reactions) depending upon changes in the aforementioned atmospheric conditions. The complex interrelated chemistry of this SO_2, NO_x, hydrocarbon, carbon monoxide system, yielding ozone and radicals such as OH, HO_2, RO_2, etc., and ultimately secondary products such as sulfate and nitrate, simply does not respond linearly to changes in input concentrations of the primary pollutants.

Where the ambient concentration of SO_2 and other primary pollutants is sufficiently high (because of high emissions and/or atmospheric stagnation), the precursor pollutant molecules will "compete" with each other for the available "oxidizing agents," and the reservoir for the "oxidizing agents" will be lowered as these agents are "used up" in the process of oxidizing the SO_2 and other primary pollutants. If this reservoir is not replenished fast enough, then the situation will invariably arise where there are more SO_2 molecules in the air or cloud water than can be "processed" by the available "oxidizing agents." In layman's terms, this rate-limiting process makes the airshed "chemically saturated" with respect to SO_2. It means that regardless of how much SO_2 is present in the airshed (i.e., independent of the ambient SO_2 concentration), the production of sulfates and/or sulfuric acid remains almost unchanged. The transformation is thus nonlinear and hence any source-receptor relationship must also be nonlinear. This situation is precisely what is believed to prevail in the eastern industrialized North American continent, or at least in the region of high SO_2 emissions (midwestern to northeastern United States), as indicated by our research discussed above.

For these reasons, the reduction in SO_2 emissions in this region called for by the pending bills would not yield a corresponding reduction in downwind deposition of sulfate and sulfuric acid within this same region and might not yield any reduction at all in such deposition within the region. Furthermore, even if any reduction in such deposition did result, it would not necessarily occur or be the same at all distances downwind. Thus, one cannot conclude, on the basis of science at the present time, that the reduction in SO_2 emissions that would be required by the pending legislation would be effective in producing the desired reduction in acid rain in the airshed in question.

4. European Research on Acid Rain Supports the Nonlinear Relationship Between Sulfur Emissions and Wet Sulfur Deposition or Sulfuric Acid Concentrations.

The above conclusions are supported by a study of Granat (1978) in Europe. He analyzed data from the European Atmospheric Chemistry Network

(EACN) on the concentration and deposition of sulfate in rain. I discussed this study in my November 5, 1981 statement to this Committee (pp. 17-18). As noted there, Granat found that a 50% increase in sulfur emissions in Europe during the 10-year period from 1965 to 1975 led to a corresponding increase in sulfur wet deposition in only a small fraction of the region covered by the network, with otherwise constant or decreasing sulfur wet deposition. Thus, in that region, a sizeable increase in sulfur emissions did not, overall, increase sulfur wet deposition.

Granat then asked where the increased sulfur emissions during those years had been deposited, and he speculated that a "probable answer" is that "increasing amounts of sulfur have been deposited in areas not covered by the network, probably eastward of major sulfur emission areas due to the general circulation over the area" (p. 419 of article). This speculation does not support the case for the pending legislation, since what we are interested in here is not the relationship between sulfur emissions and sulfur deposition on a global basis but rather within a particular geographic region -- *i.e.*, the eastern United States, a region roughly comparable in size to the region covered by the EACN. Obviously, on a global basis, there will be a linear relationship between changes in sulfur emissions and changes in the deposition of sulfur in all forms -- including dry deposition of unreacted SO_2 as well as the wet and dry deposition of sulfate -- since what goes up must come down at some place and in some form. On a *regional* basis, however, a change in sulfur emissions need not and may not produce a corresponding change in total sulfur deposition, and it certainly need not yield a corresponding change in sulfate wet deposition, for the reasons given in the preceding section.[*/]

Thus, as Granat's findings indicate, a change in SO_2 emissions even by as much as 50% in a region roughly the size of the eastern United States would not necessarily yield an equivalent or even any appreciable overall change in sulfate wet deposition in that region. As shown above, there is increasing evidence that the eastern industrialized United States does indeed exhibit such nonlinear behavior between emissions and deposition. Hence, one can conclude that the reduction in SO_2 (or NO_x) emissions in that region called for by the pending bills might not result in any measurable improvement in the acid rain situation in sensitive areas within that region.

A study by Rodhe et al. (1981) further shows that a reduction in SO_2 emissions by a given percentage will not yield a similar reduction in acid deposition or concentrations at all distances from the emission sources. Rodhe et al. developed a simplified chemical model for describing the transformation of ambient SO_2 and NO_x into sulfuric acid and nitric acid during long-range transport through the atmosphere, and compared those results with observed data from the EACN. Their model was designed to account for nineteen chemical reactions, including those that determine the concentration of the "oxidizing agents" (OH and H_2O_2) that influence the conversion of SO_2 in the atmosphere. The model recognizes that the NO_x radicals NO and NO_2

[*/] The same would appear to hold true for dry sulfate deposition, although no reliable measurement of this parameter has yet been carried out. One might expect that the amount of dry sulfate deposition would be affected both by the atmospheric conditions governing the conversion of SO_2 to sulfate and by the geographic and temporal parameters governing the dry deposition process. See pp. 14-17 below.

contribute greatly to the concentrations of those oxidizing agents and that thus NO_x emissions indirectly influence the conversion of ambient SO_2 into sulfuric acid. The researchers used this model to show how the difference between the emissions of SO_2 and NO_x in northwestern Europe in 1955 and 1975 would affect the summertime concentrations of sulfuric acid at three different travel times: 10, 30 and 90 hours.

Their model results showed that the increase in the concentration of sulfuric acid from 1955 to 1975 was significantly less than the increase in SO_2 emissions. Thus, even though SO_2 emissions for 1975 represented a nearly 70% increase over emissions in 1955, the concentration of sulfuric acid showed an increase of only 20-30% after travel times of 10 and 30 hours and only slightly higher after 90 hours. The authors stated further that this modest increase in sulfuric acid is due mainly to the assumed increase in the rate of emission of sulfuric acid itself, and that if the rate of sulfuric acid emissions had been held constant over the years, the sulfuric acid concentration after 10 and 20 hours would have decreased slightly despite the large increase in SO_2 emissions.

Undue quantitative reliance should not be placed on these findings _per se_, since they were based on an admittedly crude model. The very complex pathways and parameters involved need to be understood and quantified much more fully before the relationship between a change in emissions and a change in acid concentrations or deposition can be determined as a function of copollutants, time and geographic location in relation to major emissions areas. The importance of the study by Rodhe _et al_. is that it recognizes that the conversion of SO_2 into sulfuric acid involves very complex chemistry, rather than a simple linear relationship. As the authors concluded: "When dealing with a coupled chemical system like the [NO_x-SO_2-nonmethane hydrocarbon system] we have studied one may not assume a proportional dependence of concentrations on emission rates" (p. 139).

5. Recent Assessments in the United States Support the Conclusion That the Limiting Factor in the Formation of Acid Rain Appears To Be the Availability of Oxidizing Agents, Not the SO_2 Concentration.

I have discussed above the importance of the availability of "oxidizing agents" as a rate-limiting factor in the conversion of SO_2 to sulfate and thus in the formation of acid rain in a "chemically saturated airshed" with respect to SO_2 (such as appears to exist in the eastern industrialized United States). Rodhe et al. recognized this factor and attempted to take account of it in their model. Recent assessments in this country have likewise recognized this point.

The JASON Report on acid precipitation (Chamberlain et al., 1981) concluded, among other things, that processes involving strong oxidants, such as hydrogen peroxide (H_2O_2) and ozone, play a significant and perhaps dominant role in the conversion of SO_2 and NO_x to sulfuric and nitric acids. It noted further that NO_x plays a critical role in this process not only through direct oxidation to nitric acid but also by influencing the formation of the strong oxidants that affect the conversion of SO_2 to sulfuric acid. Its conclusions include the following:

> "[H]eterogeneous processes involving strong oxidants and droplets play a significant and perhaps dominant role in the conversion of gaseous emissions to strong acids. . . . [H]omogeneous gas phase reactions are probably of lesser significance. These preliminary findings, which are consistent with precipitation and emission data for

> the eastern United States, if confirmed by [further] experiments . . ., are of great importance to the development of any control strategies. *Even a significant reduction of SO_2 emissions*, as has already occurred in EPA Region V [the Midwest industrial belt], *may not alleviate the acid rain problems since it seems that only a fraction of the NO_x and SO_2 are converted to strong acids. The fraction converted appears to depend on the concentration of strong oxidants and their concentration is dependent on the availability of NO_x.*" (PP. I-4 - I-5) (Emphasis mine.)

Similarly, the United States State Department's Advisory Committee on Oceans and International Environmental and Scientific Affairs dealt in its meeting on January 7, 1982, with the problem of acid rain. According to an article in *Science* (Mayer, 1982): "An examination of the data confirmed the committee's opinion that sulfur dioxide is not the limiting factor in the formation of acids, including sulfuric acid, in acid rain. The limiting factor seems to be oxidizing agents, in particular NO_x. This dictates a different strategy from that recommended by the Canadian government."

6. *The Substantial Uncertainties Regarding Dry Deposition of SO_2 and Sulfates Preclude Reliable Estimates of the Effect of the Mandated SO_2 Reductions on Dry Deposition in the Northeast.*

The above discussion has dealt largely with wet deposition. The dry deposition of unreacted SO_2, as well as of fine sulfate particles, must also be considered in acidic deposition. On this subject the uncertainties are even greater than in the case of wet deposition. These uncertainties relate both to quantifying the magnitude of dry deposition and determining the relationship between such deposition and upwind SO_2 emissions at various distances downwind of those emission sources.

It is often assumed that the dry deposition of SO_2 and sulfates is proportional to the ambient SO_2 concentration. However, science has not yet reached the stage where it can measure dry deposition with any degree of accuracy, and indeed there exists no network or station measuring the amount of dry deposition. The dry deposition process is very much dependent on meteorological parameters (e.g., wind speed, atmospheric stability, etc.), plant physiological variables (e.g., stomata size, transpiration-respiration mode, etc.) and the nature of the surface. For example, the amount of SO_2 that is taken up (i.e., dry deposited) by vegetation will differ over a 24-hour period, responding to plant physiology and environmental conditions. Similarly, the ability of soils to absorb SO_2 will change, depending on soil type and again on environmental conditions. Moist soils, snow-covered ground, etc. also profoundly influence SO_2 sorption, yielding diurnal and certainly seasonal variations in the amount of SO_2 uptake by these surfaces. Considerably more research is needed to quantify these various dry deposition processes before any conclusions can be drawn.

Moreover, it is well known that the importance of dry deposition decreases with the distance of the receptor area from the emission sources, since the ambient concentration of SO_2 decreases with distance due to atmospheric dilution and ground sorption. Thus, one would expect that areas far from SO_2 emission sources -- which include many of the areas that have been identified as sensitive -- would have less dry deposition of sulfur components.

This appears to be borne out for the Adirondack area (which has been identified as sensitive and is far from SO_2 emission sources). Although dry deposition itself cannot be measured at this time, we now have some measurements of the ambient concentrations of SO_2 in that area. From these measurements, it appears that the concentration of SO_2 in the Adirondacks is below 0.3 parts per billion by volume.*/ This very low value would indicate that dry deposition of sulfur components in the Adirondacks must be significantly lower than wet sulfate deposition. Furthermore, rough calculations that I have made of dry deposition of SO_2 and particulate sulfate in the Adirondacks also indicate that dry deposition in this area is less than half the wet deposition (calculations available on request).

Because of the uncertainties relating to dry deposition, no source-receptor relationship can be established for dry deposition at this time. It seems unlikely that the reduction in SO_2 emissions required by the pending bills would produce an equivalent reduction in dry deposition in the sensitive areas of the Northeast, and one cannot predict what reduction in dry deposition in those areas would result from such action. Furthermore, even if an appreciable reduction in dry deposition should occur, its impact would

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*/ On August 6 and 8, 1980, a team from APEX (Acid Precipitation Experiment), of which I was a part, measured SO_2, sulfates and sulfuric acid particles over the Adirondack region during a period of sulfate episodic conditions. The concentration of SO_2 at Whiteface Mountain was below 0.3 ppb, while the concentrations of sulfates and sulfuric acid measured simultaneously were below 15 and 10 micrograms per cubic meter, respectively. Again, on May 19, 1982, scientists from Brookhaven National Laboratories made a test flight over the Adirondacks, in which I participated, to prepare for the upcoming field measurement program to collect and measure cloud acidity. During this test run, we again found the SO_2 concentration to be below 0.3 ppb. A systematic year-round observation of the SO_2 concentrations in the Adirondacks does not yet exist since the instrumentation to detect such low levels has just been developed and is still in the testing stage. However, it should be noted that less sensitive automatic SO_2 instrumentation located at our research station at Whiteface Mountain with a detection threshold of 3 ppb did not respond over a one-year period. With respect to sulfate aerosol, the annual median concentration of sulfate at our Whiteface Mountain research station has been determined to be 1.8 micrograms/m^3, with a mean of 3.8 micrograms/m^3. See Figure 4.

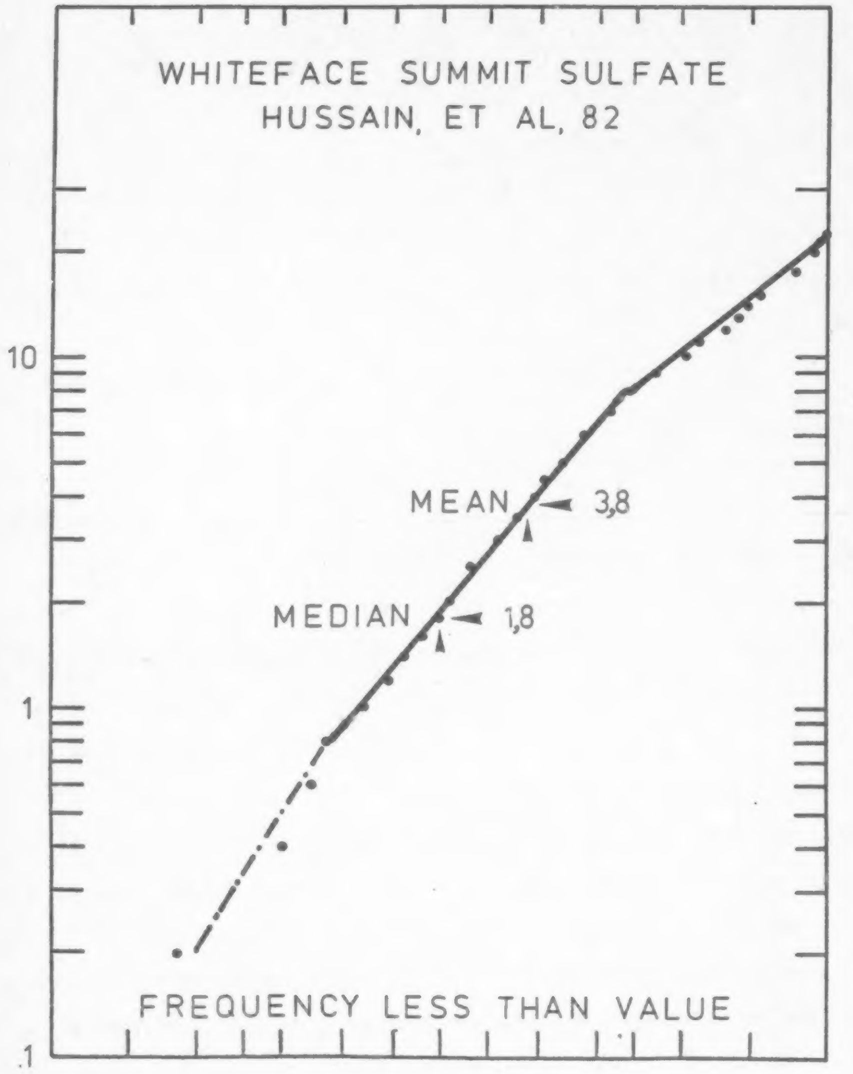
WHITEFACE SUMMIT SULFATE
HUSSAIN, ET AL, 82
MEAN
3,8
MEDIAN
1,8
10
1
.1
FREQUENCY LESS THAN VALUE
2
16
50
84
98
SULFATE, ug m^{-3}

Figure 4.

probably be small because of the dominance of wet sulfur deposition in those areas, as discussed above.

Without further research, therefore, it cannot be assumed that the strategy adopted by the pending bills would result in a measurable overall reduction in total sulfur deposition, wet and dry, in the sensitive areas of concern.

7. Long-Range Transport Models Are Not Sufficiently Accurate for Use in Policy-Making.

In recent years scientists have designed a variety of mathematical models to estimate the relationship between the amount of precursor gases (SO_2 and NO_x) emitted and the amount of wet and dry deposition of sulfur and nitrogen components on a large regional scale — *i.e.*, over long distances. Some have suggested that such regional-scale or "long-range transport" models can be used to design a control program for acidic deposition in the eastern part of the United States. At present, however, long-range transport models are incapable of establishing, with sufficient accuracy for use in a control program, the relationship between SO_2 and NO_x emissions and the wet or dry deposition of sulfur and nitrogen components over long distances (*e.g.*, in the Midwest-to-Northeast corridor). A basic problem with these models is that they assume a linear relationship between SO_2 and NO_x emissions and ultimately the wet and dry deposition of sulfur and nitrogen components, whereas, as shown above, the theoretical and observational indications do not support such a linear relationship, particularly in the eastern industrialized United States. Most current models do not recognize the interactive role of other copollutants such as hydrocarbons, carbon monoxide, ozone and other substances. In addition, because there are no satisfactory data on a number of key variables influencing the transport-transformation processes, these models treat variables in widely different and arbitrary ways. No present model has been systematically verified as predicting accurate results for downwind wet or dry deposition.

On January 18-22, 1982, a workshop of distinguished scientists that was sponsored by the U.S. Department of Energy was held to examine the source-receptor relationship in acid precipitation. The technical panel convened,*/ which was addressed by numerous investigators in the area, including myself, reached the following major conclusions, among others:

- The application of current data-driven statistical models alone cannot result in the elucidation of the source-receptor relationship in acid precipitation.
- Rigorous chemical/physical research on several basic questions can be expected to produce a useful framework within which field experiments to test hypotheses could be mounted. However, a large scale experiment probably could not be designed and conducted sooner than five years from the time of commitment to the necessary research.
- The present state-of-knowledge of the source-receptor relationship in acid precipitation precludes significant policy guidance.

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*/ This technical panel consisted of Professor John J. Cahir of Pennsylvania State University, Professor James N. Pitts of the University of California, Professor John Ross of Stanford University, Professor Sean A. Twomey of the University of Arizona, and Professor John R. Wiesenfeld of Cornell University.

In supporting these conclusions, the panel's report stated:

> "One cannot expect such a linear relationship to apply to NO_x or SO_x emissions from either stationary or mobile sources following injection into moderately to heavily polluted atmospheres" (p. 24).

* * *

> "Similar considerations may be expected to apply to the oxidation of gaseous SO_2 to form H_2SO_4 (aq.), that is, the chemistry of the source-receptor relationship involving sulfur oxides cannot, in the absence of other information, be assumed to be linear. Thus one must view with concern "first-cut" attempts to understand the deposition of sulfur-containing materials on the basis of linear chemistry. All such linear models will predict that a 50% change in SO_2 emission at source A will give a comparable 50% change in sulfate deposition at a remote receptor site B, all other things being the same. This need not be the case. Indeed, depending on a number of factors including the physical and chemical nature of oxidation processes leading to sulfates that contribute both to wet and dry deposition, as well as the physical and chemical characteristics of the atmosphere into which the gaseous SO_2 is emitted, it is possible that the material (wet or dry) being deposited at site B is already saturated with sulfate. That is to say, the chemical mechanism causing oxidation may be rate limited by a step prior to oxidation of the sulfur itself. In this case, changes in the SO_2 emission levels at source A will not be expected to cause a proportional change in the level of sulfate deposition at site B." (P. 25.)

The JASON report on acid precipitation (discussed above) reached similar conclusions. It states that "[g]iven the uncertainties in the chemical and physical processes involved we question the usefulness of such models," and that "[w]e further question claims that agreement of model results with observations are meaningful because of the large number of adjustable parameters and the ease of obtaining misleading high degrees of correlations in complex systems" (p. I-6).

The U.S. Environmental Protection Agency shares the assessment that the "'state of the art' of long-range transport models is not sufficiently advanced to be used for regulatory purposes." 47 Fed. Reg. at 10820 (March 12, 1982). The U.S. Department of Energy has likewise stated that current models assume "a linearity which is not consistent with the present evidence" and should not be used as a "basis for 'asserting emission controls to reduce acid rain impacts'" (Trivelpiece, 1981).

It would be highly premature to apply any long-range transport models to predict the effect of a reduction in SO_2 and NO_x emissions in the eastern United States on the wet or dry deposition of sulfur and nitrogen compounds within that region. Any results derived from such models are subject to very serious uncertainties and simply cannot and should not be used as the basis of a control program.

8. The Above Conclusions Are Becoming Increasingly Accepted by the Scientific Community.

In mid-November 1981, Congressman Scheuer called to Washington, D.C., a group of scientists knowledgeable in research on acidic deposition,*/

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*/ Dr. Robert W. Brocksen, Program Manager, Ecological Studies, Electric Power Research Institute;
Dr. Ellis Cowling, Program Director, EPA Acid Precipitation Program, and Associate Dean for Research, School of Forest Resources, North Carolina State University;
Dr. George Hidy, Vice President and General Manager, Western Technical Center, Environmental Research and Technology, Inc.;
Dr. Ray Jacobsen, Plant Physiologist, Boyce Thompson Institute, Cornell University;
Dr. Rudolf Husar, Washington University, St. Louis;
Dr. Gene Likens, Professor of Ecology, Section of Ecology and Systematics, Cornell University;
Dr. Orie Loucks, Science Director, The Institute of Ecology, Butler University;
Dr. Volker Mohnen, Director, Atmospheric Sciences Research Center, State University of New York at Albany.

and asked them to discuss the issue of acid rain and to relate their conclusions to the House Committee on Natural Resources, Agriculture Research and Environment. I participated in that meeting. The conclusions of this group of scientists included the following:

- Identification of the contribution of individual sources to an area affected by acid rain is not feasible.
- Wet deposition is well monitored over North America, but dry deposition is not monitored and cannot be monitored easily.
- While wet and dry deposition of sulfur are roughly equal in magnitude overall, they may vary from place to place. The amount of wet or dry deposition at any place may not be proportional to ambient concentrations.
- While the relationship between sulfur emissions and total sulfur deposition is linear on a global scale (i.e., what goes up comes down), one may not be able to predict what comes down regionally.
- For a given reduction in emissions, it is difficult to predict a reduction in deposition or acidification.

In addition, as discussed above, the distinguished technical panel convened on January 18-22, 1982, concluded that there is no linear relationship between SO_2 or NO_x emissions and acid rain and that current models are unable to elucidate a source-receptor relationship in acid rain. It is worth repeating that this panel concluded that "[t]he present state-of-knowledge of the source-receptor relationship in acid precipitation precludes significant policy guidance" (p. 6).

Some have cited, as support for the pending bills, a 1981 report of the National Academy of Sciences' National Research Council Committee on the Atmosphere and the Biosphere (NRC, 1981). Among other things, that report concludes (p. 181) that control of SO_2 and NO_x emissions "can significantly reduce the rate of deterioration of sensitive freshwater ecosystems," that it is desirable for such areas to have pH values no lower than 4.6-4.7, and that in the most seriously affected areas "this would mean a reduction of 50 percent in deposited hydrogen ions." Because I am not an expert on the ecological effects of acid rain, I am in no position to comment on whether the ecological damage caused by acid rain justifies the report's recommendation of a 50% reduction in deposited hydrogen ions for those areas most seriously affected. However, it is wholly erroneous to assume that such a reduction in deposited hydrogen ions would result from a reduction in SO_2 emissions of 50% or 10 million tons. As shown above, such a reduction in SO_2 emissions in the eastern industrialized United States, particularly in the Midwest, would probably not yield an equivalent reduction in acid rain in the Northeast and might have no measurable effect upon acid rain in the ecologically sensitive areas in that region.

In recognition of these uncertainties, the National Academy of Sciences has established another committee ("Committee on Transport and Transformation Chemistry in Acid Deposition," organized under the auspices of the Environmental Studies Board of the Commission on Natural Resources, National Research Council) to prepare a statement of what is currently known and not known about the physical and chemical processes relating emissions of precursor gases to wet and dry deposition of acidic substances. The committee is studying this subject taking cognizance of the legislative proposals addressing acidic deposition. Its report will also outline the research that should be done to improve understanding. The report of this committee has not yet been released.

9. Conclusion

I hope that I have demonstrated the substantial scientific uncertainties concerning the processes involved in causing acidic deposition. Until science has a much better understanding of those processes, an effective control strategy for acidic deposition cannot be designed. There is simply not enough reliable information to allow one to predict with any accuracy the extent, if any, to which the reduction in SO_2 and NO_x emissions called for by the pending legislation would produce a reduction in acidic deposition in sensitive areas. As noted above, the limited research that has been done indicates that, in the eastern industrialized United States, such a reduction in emissions would probably not produce an equivalent reduction in acidic deposition and might not yield any appreciable reduction in acid rain at all in the sensitive areas.

Such a reduction in emissions would be extremely costly, both in terms of utility costs and in the loss of many coal mining jobs in certain parts of the country (mainly the Midwest). While such an economic and social burden might be tolerable if the mandated control strategy would be effective in substantially ameliorating a potentially serious acid rain problem, the lack of any reliable evidence -- or even likelihood -- that the mandated strategy would have that beneficial effect in sensitive areas would seem to make the controls unwarranted. Moreover, the theory is now emerging that reducing SO_2 and NO_x emissions might have a very serious side effect: Due to the complex interaction that exists among all substances suspended in the atmosphere, such reduction in SO_2 and NO_x could result in a significant increase in the ozone concentration in certain regions downwind of emission sources. Unless the concentration of reactive hydrocarbons in the atmosphere is also reduced, such an ozone increase appears to be inevitable. As is well known, ozone is a serious health threat and a known plant toxin. Damage to crops (managed land) by ozone at current levels has been recently estimated to be of the order of 3-4 billion dollars per year. It appears to me that the greatest risk a policy-maker can take at this time is to commit the country to a limited control program at a considerable economic and social burden with no evidence or likelihood that it would be successful and with the chances of aggravating an existing health hazard.

It seems likely that in order to achieve any significant reduction in acid rain in sensitive areas, one would have to reduce SO_2 emissions by much more than 50%. This enormous emissions reduction simply cannot be realized with existing technologies and economic resources. On the other hand, any quick technological fix for emission reductions, such as those proposed in the pending bills, would impose significant economic and social penalties on society with the false promise of having resolved a crisis. What is called for at this time, in my opinion, is not a "control" strategy for "acid rain," with quick fixes and a patchwork of dubious value clustered into Clean Air Act amendments, but intensive research efforts on the processes involved in producing wet and dry acidic deposition and on their effects and an economic incentive plan for the orderly replacement of existing, older power plants with better controlled, more efficient power plant technologies.

The only remaining question is the time in which a reduction in acidic deposition must be achieved before irreparable damage in sensitive areas will occur. Based on my inquiries, no effects researcher is willing to predict this time period. Although I am not an expert in effects research, I am led to believe, judging from the Scandanavian experience, that the rate of change in the observable effects of acidic deposition occurs over decades, rather than years, and it is very likely that the time constant will be different for different effects (aquatic, terrestrial, forest, etc.). An intensified acid rain research program is needed to resolve these issues and to monitor changes in the ecosystem.

In the meantime, what actions should be taken now, apart from intensified research to remove our ignorance? I understand the eagerness of Congress to respond to the widespread public demand for quick corrective action. Unfortunately, atmospheric science is not yet in a position to aid in the design of an effective control strategy for acidic deposition. Tinkering with existing, older power plants by retrofitting those plants with flue gas desulfurization systems will only prolong their inefficient life and, even after fully implemented, might well not result in sufficient emissions reduction to produce the desired reduction in acidic deposition in sensitive areas. Even after the emissions reductions mandated by the pending bills have been achieved, we might very well still not have achieved the level of wet and dry deposition that effects researchers consider desirable.

On the other hand, new technologies for the conversion of coal to energy, such as integrated coal gasification combined-cycle power plants, are more efficient and considerably less polluting than present commercially available power plants (and can burn even the highest-sulfur coal). I am convinced that, over time, economic and environmental pressures will force the implementation of such new technologies in any event. What is needed now is a forceful economic incentive plan for the implementation of these new technologies over a period of, say, 20 years. This alternative strategy will not only offer economic benefits but will ultimately provide a solution to the environmental stress caused by acidic deposition. Such sensible action would offer technological leadership that is so desperately needed by the country at this time, even if it would require a longer time for implementation. Ultimately, it will be money and time well spent.

Returning to the pending bills, the unfortunate fact is that they are attempting to regulate without any evidence or even likelihood that the control program established would have the desired effect. Harold Macmillan once observed that politicians have to run hard to catch up with scientists. But in this instance, it is the reverse; politicians better slow down and let scientists catch up with them.

Volker Mohnen

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ENVIRONMENTAL DEFENSE FUND

TESTIMONY OF DR. MICHAEL OPPENHEIMER

Before The

SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

May 25, 1982

Mr. Chairman, my name is Dr. Michael Oppenheimer. I would like to thank you for the invitation to testify here today. I am the senior scientist in the New York office of the Environmental Defense Fund, a national non-profit organization dedicated to the preservation of the human and natural environment. I joined EDF over a year ago after ten years as an atmospheric physicist at the Harvard-Smithsonian Center for Astrophysics at Harvard University.

Mr. Chairman, I shall address the question of the extent of our scientific understanding of acid deposition. In my remarks today, I shall pay particular attention to recent scientific evidence on the relationship between pollutant emissions and acid deposition. Both my own research, and the research of others, has led me to conclude that reductions in sulfur emissions will lead to nearly comparable reductions in acidic sulfur deposition over the eastern United States. I further conclude that long range transport of sulfur pollutants over many hundreds of miles is a major source of acid deposition over parts of the Northeast.

Here is an outline of the state of scientific understanding of acid deposition:

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(1) Precipitation over most of the eastern United States including the Southeast, is abnormally acidic, ranging up to 20 to 40 times more acidic than normal on an annual average basis in parts of the Northeast.[1,2] Acid rain also has appeared in the Rockies [3] and is widespread in California.[4] Rainfall in the East is primarily a dilute solution of sulfuric acid while in the West it may be primarily either nitric acid or sulfuric acid.[1,3,4,5] There is no question that precipitation acidity substantially exceeds the natural background value.

(2) Atmospheric loading of sulfur and nitrogen compounds is by far the major source of acid rain. In eastern North America, atmospheric loading of sulfur and nitrogen due to human industrial and transportation activity far exceeds that from natural sources. Natural sources of sulfur in the eastern U.S., much less than one million tons per year, are far too small to account for the sulfur, mostly in sulfuric acid, actually observed in precipitation, about two million tons per year. For comparison, man-made sources of sulfur amount to over 11 million tons per year [6,7,8] (equivalent to 22 million tons of SO_2). Approximately two-thirds of the total U.S. sulfur loading is from power plants, which also provide nearly 30% of the atmospheric loadings of oxides of nitrogen (NO_x). Emissions from the transportation sector are another major source of oxides of nitrogen, providing over 40% of the national total.[9] Since, on average, nearly three-fourths of the acid in eastern U.S. precipitation is due to sulfuric acid,[1] and since

utilities are responsible for more than 70% of eastern U.S. sulfur emissions,[7,8] it is certain that utilities are the major source of acid rain in the East. The recently issued report of the National Academy of Sciences confirms this conclusion.

(3) The detailed mechanisms for the transformation of sulfur dioxide (SO_2) and NO_x emissions into acid rain are not completely understood, but there is absolutely no doubt that the transformation occurs. I have spent most of the past year researching this transformation. A general description of the process is the following: SO_2 and NO_x emissions from various sources are mixed into the lower atmosphere with moisture and other pollutants. Out of this chemical soup, various nitrates and sulfates are produced, among them nitric acid and sulfuric acid. Some of this material is periodically rained out in precipitation and some remains suspended as fine particles. Many of these fine particles as well as untransformed sulfur dioxide molecules are eventually deposited as dry acid material in a process called dry deposition. In many areas, dry deposition is a major sulfur deposition mechanism. Thus, the acid rain, dry deposition and fine particle problems are intimately related.

Let us examine the transformation process more closely. There are essentially three pathways to the formation of sulfuric acid in the atmosphere: oxidation of sulfur dioxide in the ambient gas, in cloud and rain droplets, or on particle surfaces. With the exception of the near-source region, particle surface reactions appear to be an insignificant contributor.[10] However, substantial evidence has accumulated that nearly all SO_2 processed through rainstorms is converted to sulfates, and that this process is the major source of precipitation sulfuric acid.[11,12,13,14] My own research[14] demonstrates that for this portion of the sulfuric acid produced, the relationship of airborne concentrations of SO_2 to sulfuric acid in precipitation is nearly one-to-one. I estimated that a 50 percent emissions reduction will produce more than a 40 percent reduction in precipitation sulfuric acid produced by this route over the year in the eastern United States.

The other pathway to sulfuric acid production is the gas phase oxidation of sulfur dioxide in plumes and in the ambient air. It has been demonstrated that the levels of sulfuric acid produced by this pathway also respond nearly linearly to SO_2 concentration changes.[15,16]

I conclude, therefore, that the relationship between sulfur emissions and levels of sulfuric acid in precipitation is, indeed, very close to one-to-one for substantial emissions reductions no matter which pathway is dominant. There is no evidence of any significant oxidant limitation effect on sulfuric acid formation on a regional and annual basis. Furthermore, since dry deposition of SO_2 appears to operate in a linear fashion on a regional average basis,[17/] it is clear that total acidic sulfur deposition* will vary nearly linearly with sulfur emissions on a regional average basis. I have appended a summary of my recent article on this subject to this testimony. My conclusions are consistent with the results of other recent research.[18/]

(4) Long range transport plays a vital role in the distribution of acid rain, sulfur dioxide, and fine particles about the country. Recent atmospheric modeling summarized in the report of the Working Group on Atmospheric Modeling Under the U.S.-Canada Memorandum of Intent on Trans-Boundary Air Pollution[19/] and the Second Report of the U.S.-Canada Research Consultation Group on the Long-Range Transport of Air pollutants[20/] provides a general picture of this process. There is little doubt that most of the wet deposited sulfur including sulfuric acid reaching the Adirondacks, for instance, originates outside the Mid-Atlantic region, largely in the Ohio River Basin and the Upper Midwest. The contribution of

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* The SO_2 and NO_x which are not converted into acids in the atmosphere and deposited in rainfall are still a source of environmental damage. Unconverted SO_2 is eventually deposited on land, water, plants, and trees and much of this material is then converted to acid. Suspended fine particles present a health hazard when inhaled by humans. Much of the fine particulate matter is eventually deposited on leaves, soil, and surface water and, along with the dry sulfur dioxide, contributes perhaps an additional 30% to ecosystem acidification. Thus, almost all of the SO_2 originally emitted ends up on the earth's surface in one harmful form or another. In addition to a decrease in the acidity of precipitation, therefore, a decrease in SO_2 emissions will reduce environmental damage caused by dry deposition. The reduction in dry deposition of SO_2 appears to occur in direct proportion to the reduction in sulfur dioxide emissions.

U.S. sources to sulfur deposition in Canada is about equal to the contribution of Canadian sources to sulfur deposition in Canada. Furthermore, the U.S. contributes five times more to deposition in in Canada than Canada does to deposition in the U.S.[20]

My own research also throws some light onto this question. About 22 percent of sulfur emitted in the eastern U.S. is detected in rainfall in eastern North America. Because rainfall is rather infrequent, the survival time for sulfur dioxide in the atmosphere must be very long, or much less sulfur would last long enough to appear in rainfall. This survival time is, in fact, long enough that prevailing winds must carry a substantial fraction of the sulfur for distances of 500-1000 miles before it is deposited.[16]

There has been at least one study widely circulated which purports to show that local sources in the Northeast constitute the main source of sulfates in that region.[21] This report, by researchers at PEDCo Environmental, Inc., commissioned by the Department of Energy, has been critiqued by myself and others [22] who find that the assumptions made concerning the rate with which sulfur is transformed are without basis and at odds with the best scientific evidence. Using more reasonable assumptions, even the model used in that report would tend to substantiate the findings of the Working Group that 70 percent or more of the sulfate over the Adirondacks originates outside the local region. (The report, for instance, assumes a degree of sulfur transformation in power plant plumes which is three times larger than generally accepted.)

Further evidence of the significance of long-range transport comes from satellite photographs of pollution episodes combined with simultaneous ambient air measurements.[23] These measurements show the large scale relationship of sulfates, ozone, TSP, and reduced visibility over the East. Trajectory analysis also has demonstrated that specific instances of atmospheric stagnation in the Midwest are correlated with enhanced sulfate levels at later times in the East.[24] Research performed in conjunction with the SURE studies has confirmed the existence of long-range transport of sulfates.[25] The reality and significance of long range transport is no longer in doubt.

(5) Historical data on precipitation acidity over the last 20-30 years is not of high quality. However, these data do suggest a relationship between the construction of taller stacks and the spreading out of the region of abnormally acidic rainfall. Precipitation pH data from the 1950's, even when corrected for the possible neutralizing effects of drought-generated dust, indicate a spreading of the region affected by acid precipitation,[26] in spite of the fact that total U.S. sulfur emissions have not changed much. However, the fraction of emissions generated by utilities commonly emitting through tall stacks has increased markedly in the last several decades.[9] Furthermore, the few measurements made in the 1930's indicate that rainfall in the Northeast was much less acidic at that time.[27] A glance at a map of precipitation acidity in the U.S. clearly shows the intimate association of fossil fuel

emission sources and abnormally acidic precipitation.[1,28] Most significantly, recent studies [29,30] indicate that the decrease of sulfur emissions in the Northeast over the last decade, has in fact been accompanied by a decrease in sulfate deposition levels, a fact which should lead us to anticipate the success of an emissions reduction strategy.

(6) Arguments have been made that low rainfall pH measurements at a few remote island stations [31] mean that rainfall is normally very acidic. I would like to emphasize the complete irrelevance of this argument to the eastern U.S. where man-made sources of acidity far outweigh natural sources. Furthermore, some natural sources of sulfur are more significant for these island stations than for the U.S. mainland. Finally, these observations may simply indicate the importance of global transport of pollutants at certain locations since some remote stations report normal pH levels of 5.6.[31]

In summary, it is certain that precipitation in the U.S. is now far more acidic than it would be in the absence of human activity. The primary source of this acidification, especially in the eastern U.S. is utility emissions, mainly of sulfur dioxide. There is now strong evidence that substantial reductions in utility sulfur dioxide emissions will lead to comparable reductions in wet sulfur deposition, precipitation acidity, suspended sulfates and total sulfur deposition. It is certain that the problems associated with sulfur deposition in its various forms cannot be alleviated without reductions of utility SO_2 emissions. However, mobile sources continue to be a significant component of this problem, and their relative importance will increase as utility emissions are reduced.

My conclusion, as a scientist, is that enough is known about the sources of acid rain to initiate a long-term control program aimed at the abatement of emissions of sulfur dioxide and oxides of nitrogen. Since utility sulfur dioxide emissions are the major single source of the precursors of acid rain, and since sulfur oxides appear to pose a greater threat to the environment than other components of acid deposition,[32/] these emissions are the logical initial target of any control strategy.

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ENVIRONMENTAL DEFENSE FUND

SUMMARY OF "THE RELATIONSHIP BETWEEN SULFUR EMISSIONS AND SULFATE IN PRECIPITATION"

by Michael Oppenheimer

The acidity of rainfall in eastern North America arises from sulfates and nitrates which originate almost entirely in anthropogenic emissions. The largest contribution to rainfall acidity comes from sulfates which account for about 70 percent of the hydrogen (acid) ions in rainfall. In addition, ammonium ions associated with sulfate in rainfall act as an acid in the terrestrial ecosystem. Therefore, precipitation sulfate is regarded as the most significant source of ecosystem acidification on a geographical and annual average basis. The above article addresses the question: if emissions of sulfur (sulfur dioxide) are reduced by a given amount, how much reduction will occur in precipitation sulfates, and therefore precipitation sulfuric acid and ammonium sulfate, on an annual and geographical average basis over the eastern United States and eastern North America.

The article examines recent evidence collected from precipitation monitoring networks and from observations of airborne sulfates and acidity. This evidence, along with recent laboratory studies, strongly suggests that sulfates in precipitation are formed mostly by absorption of sulfur dioxide into cloud droplets

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and subsequent oxidation in the droplets to sulfates, including sulfuric acid. Gas phase reactions to form sulfuric acid do not appear to be significant. Hydrogen peroxide is a reasonable candidate for the oxidant which converts sulfur dioxide to sulfate in droplets.

By comparing the observed wet sulfate deposition in precipitation as determined by monitoring networks with total sulfur emissions, it was possible to determine the fraction of sulfur emitted in the eastern United States which is converted to sulfate and deposited in precipitation on land. This fraction is 22 percent. However, only about one-third of airborne sulfur dioxide is ever passed through precipitating clouds since it is generally dry deposited in between precipitation periods. Furthermore, some SO_2 is deposited over the ocean. When these effects are accounted for, one determines that the actual efficiency of conversion of SO_2 in sulfate is close to one for that part of the SO_2 which is passed through precipitating clouds. Most of the sulfur dioxide which can be oxidized is oxidized to sulfate in clouds and precipitation; most SO_2 which enters significant precipitation systems comes out as sulfate in precipitation. As a result, the relationship of changes in emissions to changes in sulfate in precipitation is not far from 1 to 1. Therefore, a reduction in sulfur dioxide emissions will be reflected in a precipitation sulfate reduction by a relationship which is not far from 1 to 1. More specifically, a uniform reduction of 50 percent in eastern United States emissions will yield a reduction of between 40 and 50 percent in precipitation sulfates resulting from those emissions, on an annual average basis over eastern North America, assuming similar meteorological conditions to the period studied (1977-79). When wet plus dry deposition of SO_2 is considered together, we note that a uniform 50 percent emissions reduction should produce nearly a 50 percent reduction in total sulfur deposition (ignoring the small contribution from dry deposition of sulfate particles).

This research shows that a 50 percent emissions reduction will produce large and nearly comparable reductions in precipitation sulfates and measurable improvement in the acidity of precipitation. The Mitchell bill proposes a 63 percent reduction in utility emissions. Since these emissions are relatively more effective in producing acid rain than low level sources, even larger sulfate reductions can be expected than would occur from a 50 percent reduction in all sources. Such reductions will be in addition to reductions in dry SO_2 depositions.

Previous to this research, some scientists had suggested that the wet sulfate reduction proceeding from a 50 percent emissions reduction could be entirely negligible.

New evidence on source areas of pollution aerosol in the Northeast

(A statement for the 25 May 1982 hearing on causes and effects of acid precipitation, Dirksen Senate Office Building, Washington, D.C., sponsored by the Senate Committee on Environment and Public Works)

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A crucial aspect of the entire acid-precipitation question is its scale of regionality. To effectively control any pollutant, one first has to determine the regionality of its sources and transport. After establishing the boundaries of the region to be controlled, one can begin to control, normally with the largest sources first.

A decade ago, most air-pollution problems were considered to be local. Since then, it has been increasingly recognized that certain aspects of air pollution are regional in scope, and can sometimes reach scales of hundreds of miles or more. Acid precipitation is one of these regional phenomena. Thanks in large measure to studies of long-range transport of air pollution and subsequent acidic deposition in southern Scandinavia, where episodic transport of precursor pollutants for 600 miles from central Europe is common, it is now recognized that air pollution in the eastern United States may be similarly regional. In the case of acidity, the Midwest is often identified as the source of much of the deposition in the Northeast.

These developments are indeed laudable. Long-range transport of pollution aerosol is real. My personal feeling is that it is even more common and widespread than is recognized today. An extreme example is that of Arctic haze, which is composed largely of aged pollution aerosol transported 3000-6000 miles from Europe and Asia to the Arctic every winter and spring.

Evidence in support of the long-range explanation of acid precipitation in the northeastern United States is massive and convincing. The distances of transport from the Midwest, roughly 600 miles, are the same as those documented from central Europe to southern Scandinavia, and are trivial compared to those for the Arctic.

But is the long-range explanation really the correct one for the Northeast? During the last eight months or so, I have accidentally uncovered counterevidence which suggests that, while there is certainly routine long-range transport into much of the Northeast, its importance relative to local (northeastern) sources may often be considerably less than previously imagined. Today, I will review this new evidence and its implications for the control of acid precipitation.

At the outset, I wish to state several things for the record: (1) I am a relative newcomer to the field of acid precipitation *per se*, having been in the field for less than a year; (2) The evidence to be discussed here was generated as a spinoff from research in Arctic air chemistry, rather than from a formal funded project in the Northeast; (3) I have no published articles on acid precipitation; (4) My evidence is preliminary and incomplete; (5) It deals with aerosol, not precipitation; (6) It deals with trace elements in the aerosol, not with its acidic component; and (7) It is now recognized that acidic aerosol is not the major source of acid precipitation.

On the other hand: (1) I have been studying trace elements in pollution aerosol in various areas of the world for more than a decade, and have published a variety of articles in this field; (2) My new evidence involves a way to assess the scale of regionality of pollution aerosol that was developed from these studies and has not been available before. Whereas it was previously not possible to directly assess source areas of any constituent of the aerosol, we can now do it for at least a portion of the aerosol. This elemental tracer approach to source areas (discussed in the next paragraph) is generalizeable in principle, and will ultimately be applied to both acidity and gaseous SO_2.

In connection with our studies of the Arctic aerosol, we have learned that regional-scale source areas of pollution aerosol have characteristic trace-element signatures which may be used as indicators of the origin of aerosols downwind, even over distances of hundreds to thousands of miles from the sources. Although these signatures undoubtedly involve many elements, we have to date used only two, manganese (Mn) and vanadium (V). The Mn/V ratio, or more properly the ratio of noncrustal Mn to noncrustal V, is about ten times greater in the Midwest than in coastal regions of the Northeast, between roughly Boston and Washington. The reason for this lies primarily with V. Whereas the concentrations of noncrustal Mn (whose exact sources are unknown at present) are only slightly higher in the Midwest than in the Northeast, the concentrations of noncrustal V are several times higher in the Northeast (because of combustion of large amounts of residual oil, much of which comes from Venezuelan crude oils that are unusually enriched in V). By measuring the Mn/V ratio in northeastern aerosol, one can determine in principle whether it has originated in the Northeast, in the Midwest, or in some combination of the two regions.

We sought to use this approach to confirm the midwestern origin of northeastern aerosol, particularly during episodes of high sulfate, which occur commonly during summer and have been used by others as the basis for judgments on the importance of long-range transport in the Northeast. If the sulfate, acidity, and associated pollution aerosol really came from the Midwest, the aerosol of these episodes should carry with it high (midwestern) Mn/V ratios. By contrast, aerosol between episodes should have much lower (northeastern) Mn/V ratios.

At this time, we have data from four locations in the Northeast which can be used to understand the origins of its aerosol. By far the largest set of data comes from Narragansett, Rhode Island. It totals well over 200 aerosol samples taken during nearly three years. A subset of 60 samples, representing nearly one year, was selected for illustration. They showed that at least the Mn and V of Rhode Island were strongly northeastern in origin in almost all the samples, independent of season, wind pattern, and sulfate concentration. In particular, aerosol during sulfate episodes was nearly as local in origin as was that between episodes. Within the Northeastern signature, shadings apparently representing the Boston and New York areas could be seen, in addition to the signature of generalized southern New England aerosol, which was the most common case.

Needless to say, we were greatly surprised by these results. The intensity of local influences on Rhode Island aerosol was unexpected by everyone. These new findings and their implications were communicated in an informal statement of 23 November 1981, which has since become the subject of great discussion and debate. Although criticisms have been raised (see below), the sense of the results has held up (in my judgment), and is supported by independent data from other studies.

The Rhode Island results can be placed in better perspective by the other three data sets. One set, from New York City during summer, shows a local aerosol which is very reproducible from day to day, as might be expected in the middle of a strong source area. The Mn/V signature of this aerosol appears to be detectable in Rhode Island whenever the wind comes from the southwest, and is the second most frequent kind of aerosol found there.

The third data set comes from High Point, New Jersey, also during summer, and is very different from those of Rhode Island and New York. Mn/V ratios of High Point vary greatly from sample to sample, and can be either midwestern or northeastern, depending on the air flow. The most common signature was similar to that of New York City, which would seem to indicate a general mid-Atlantic influence on High Point. To us, it is reasonable that High Point, which is 200 miles inland from Rhode Island, should show more frequent midwestern-like aerosol than Rhode Island does.

Recently, we have obtained similar results from Glen, New York, a site 40 miles west of Albany. The Glen aerosol can be either northeastern or midwestern in character, depending on air flow. Glen is almost due north of High Point, and is also situated roughly on the border between the coastal V-rich strip and the interior V-depleted regions.

We interpret the results from these four sites to mean that there is no such thing as "the" Northeast. Rather, the Northeast is comprised of at least two atmospheric subsystems with different sources of aerosol. The coastal Northeast, represented by Rhode Island, experiences northeastern, or local, aerosol most of the time. Beginning 200 miles or so inland, a transition zone is encountered which can experience either northeastern or midwestern aerosol, depending on the history of the particular air mass. Farther westward, an area is reached which receives midwestern aerosol most of the time. We expect but cannot yet prove that western New York State, probably including the Adirondacks, is in this region. The aerosol of northeastern New England (Vermont, New Hampshire, Maine) is still unstudied. In short, aerosol composition in the Northeast varies systematically from east to west, with increasing effects of midwestern sources seen toward the west. North-south gradients remain undetermined.

There are several potential problems with this new way of studying aerosols which have been raised by us and others, including: (1) variable composition of emissions from source areas; (2) changes of elemental ratios during transport due to different rates of wet and/or dry deposition of the constituent elements; (3) artificial lowering of Mn/V ratios of midwestern aerosols as they are transported into the V-rich coastal regions; and (4) general inability of Mn and V to trace the origin of sulfate, for the former are primary (emitted directly as aerosol), whereas the latter is secondary (emitted as a gas and formed as aerosol in the atmosphere), and hence is of more distant origin. Without minimizing any of these objections, they can all be answered: (1) At least on the time scale of a few days, we have observed that Mn/V ratios in large source areas are remarkably stable; the order-of-magnitude separation between Northeast and Midwest signatures allows considerable variations within each region; (2) Little data exist with which to evaluate this potential problem. Based on differences between particle-size distributions of noncrustal Mn and V, and on the general physical nature of scavenging of aerosol particles in clouds, differences in deposition of Mn and V would not be expected to be larger than factors of 2-3 during transport, which is much less than the initial order-of-magnitude differences between the two regions; (3) While there is certainly a tendency for this process to occur, the agreement between New York aerosol and that observed both at High Point and Rhode Island suggests that aerosol found in the Northeast actually originates in the Northeast, and is not just midwestern aerosol with a dose of northeastern V; (4) There is now considerable evidence that sulfate is actually pseudo-primary, both in terms of its primary emissions in winter and the rapid decay of its parent SO_2 in summer. The more nearly primary that sulfate is, the better it can be traced by Mn and V. We suspect that on a scale of 100-200 miles or more, the sources of sulfate are very similar to those of Mn and V.

Implications of these data relevant to this hearing are:

(1) A 31-state regulatory region for acid precipitation may be too large. According to our data, the prevalent distance scale, at least for pollution aerosol, is roughly 200 miles.

(2) The eastern United States may be composed of two or more source-receptor regions, not just one. If so, appropriate emission standards for each region may differ, as dictated by the ecological characteristics of the individual receptor areas.

(3) Consequently, a single emission standard for SO_2, as proposed in the bills currently before Senate and House, may not be justified atmospherically.

(4) Strong controls placed on midwestern sources of SO_2 may not affect acid deposition in regions of the Northeast which are not directly in the midwestern receptor area, such as coastal New England. To reduce acidity in these regions, northeastern emissions, which are already low, may have to be reduced still further.

In conclusion, then, our new data have suggested that the system of sources and transport of pollution aerosol in the Northeast is considerably more complex than was recognized previously, and that substantial portions of the Northeast may be influenced primarily by northeastern rather than midwestern aerosol, even during sulfate episodes. If this view is correct, it casts considerable doubt on the popular view of the Midwest as the dominant source of acidity throughout the Northeast. From recent contacts with scientist working in other aspects of acid precipitation, I have learned that similarly large uncertainties exist in many of their areas, the depths of which are not generally appreciated by nonspecialists. It is my impression that many of these problems can be resolved with a few years of intensive effort. Considering the decades or centuries that acid precipitation has been with us, a few more years' wait is not critical. Now that the Congress has passed the Acid Precipitation Act of 1980 and has called for a decade of concentrated research, I see no scientific reason why we should assume the answers before the research has hardly gotten under way. To legislate strong controls on certain pollutants before the entire system is understood, especially when those controls are focused on one area of the country, seems to me to be several years premature at best and potentially disastrous economically at worst. The left hand has just given us ten years, but the right hand wants to act now. There is no ecological crisis that demands such rapid action. Now that you have at last given us the means to work on this problem, please give us the time!

ACID RAIN: A TECHNICAL INQUIRY

THURSDAY, MAY 27, 1982

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
Washington, D.C.

The committee met at 10:05 a.m., in room 4200, Dirksen Senate Office Building, Hon. Robert Stafford (chairman of the full committee) presiding.

Present: Senators Stafford, Chafee, and Mitchell.

Senator **STAFFORD**. The Committee on Environment and Public Works will please come to order.

The Chair is informed that there is a Democratic caucus in progress and that, in consequence, the ranking member, Senator Randolph, and one of the two Senators who wished to speak to us this morning are unable to be here at the moment. But it is the Chair's intent to get started because I anticipate the possibility of rollcall votes interrupting our proceedings this morning.

I am particularly happy to see Senator Mitchell has arrived. I can thank him publicly now for concluding the proceedings on Tuesday. And Senator Chafee is here.

The Chair has no opening statement this morning. Senator Mitchell, do you have any?

Senator **MITCHELL**. No, Mr. Chairman.

Senator **STAFFORD**. Senator Chafee, do you have any opening statement?

Senator **CHAFEE**. No, I don't; we look forward to hearing our distinguished witnesses, including our lead witness.

Senator **STAFFORD**. Yes, indeed.

Senator **CHAFEE**. We are delighted to see you here.

Senator **STAFFORD**. Yes; the committee is very happy indeed to have our close friend as well as very able Senator here in the room with us as the lead witness. Senator Danforth, we would be very happy to hear your statement at this time.

STATEMENT OF HON. JOHN C. DANFORTH, U.S. SENATOR FROM THE STATE OF MISSOURI

Senator **DANFORTH**. Mr. Chairman, thank you very much. I appreciate the opportunity to testify this morning on the problem of acid rain. I also want to commend you for scheduling these 2 days of hearings on current scientific evidence concerning this phenomenon. They are particularly timely and relevant to the issues that concern me.

The fact that acid rain poses a threat to the environment, I think, is no longer seriously in dispute in the scientific community.

At the committee's hearing Tuesday, Mr. Chairman, you pointed out quite dramatically the level of consensus on this issue. There is general agreement that oxides of sulfur and nitrogen are transported, sometimes hundreds of miles from their sources, and transformed into acidic precipitation. When that precipitation falls on certain naturally fragile regions, it can take the life from lakes and streams, damage forests, and corrode the works of man.

I share your concern about this issue, Mr. Chairman, and I joined with Senator Mitchell last fall as an original cosponsor of S. 1706 to demonstrate that concern. Simply to study the problem further is not enough. We must begin immediately to take remedial action.

But I was not satisfied last fall that S. 1706 was the final answer to the problem, and upon further reflection I am even less satisfied today. While I agree with its general approach—that is, requiring a major reduction in sulfur dioxide emissions on a regional basis—I am not convinced that the bill is focused tightly enough or that it spreads the cost of compliance in a fair and evenhanded way.

As the committee heard Tuesday, recent scientific findings suggest that local sources of sulfur dioxide may play a far more important role in the creation of acid deposition than distant sources. Dry deposition appears to be tied particularly closely to its point of origin. This is not to say that long-range transport does not occur. It is to say that all sources are not alike, all sources are not equally important. And because the adverse effects of acid precipitation are chiefly felt in certain susceptible regions, these findings bear significantly on the proper structure of an equitable control strategy.

S. 1706 does not attempt to fine tune its approach to sulfur dioxide reductions. It simply mandates a 10 million ton cut by the 31 States from the west bank of the Mississippi to the Gulf of Mexico. My purpose in coming here today is to suggest that that is not good enough, that the committee can do better than this blunderbuss approach. The fact of the matter is that enactment of S. 1706 as written would result in some States within the region suffering a massive economic shock from the cost of reducing their sulfur emissions, while other States—including some of the main beneficiaries—would bear none of the cost.

My own State of Missouri puts a lot of sulfur into the atmosphere, and some reduction may indeed be warranted. But Missouri is a long way from the Adirondacks—a long, long way—and it is not at all clear that Missouri's sulfur is contributing in any significant way to the problems of Vermont. Yet S. 1706 would impose on Missouri a greater level of sulfur reduction [80 percent] than it would on any other State. This would carry an enormous price tag. State air quality officials in Missouri have surveyed the State's utilities, and they conclude—conservatively—that electric rates would rise by at least 25 percent because of S. 1706 alone. That amounts to $500 million a year—or $100 a year for every man, woman, and child in the State.

I want to do something about acid rain. I refuse to sit back and say, "Study, study, study." But I cannot support a bill that imposes such an enormous burden on my State without clear-cut benefits to show for it.

Accordingly, I am today introducing an alternative to S. 1706, a bill that is completely identical in all but two major respects.

First, it reduces the size of the acid deposition impact region from 31 States to 22—removing from the region the Western and Southern States most distant from the areas that are vulnerable to acid rain. These nine fringe States—whose contribution now to the problem is unclear—would constitute a secondary region.

After the 2-year study of long-range transport required by section 182(b) of both bills, the EPA administrator could combine the primary and secondary regions if scientific evidence clearly warranted such action—thus recreating the 31-State region in S. 1706.

The sulfur reduction requirement set in S. 1706 [10 million tons] would be scaled back to 7.5 million tons for the primary region but would revert to 10 million tons if the two regions were combined.

Second, my bill would create an acid deposition reduction trust fund. Every electric utility within the region would pay into this fund 3 mils per kilowatt-hour sold. The money then would be used to offset the cost of complying with the sulfur reduction requirements in the bill. States would receive grants based on the actual expense incurred by utilities within their borders.

The cost of S. 1706 is commonly estimated at up to 5-percent for the entire region. Clearly, that cost would fall extremely unevenly as S. 1706 is currently structured. My approach would spread out the costs across the region at approximately the 5-percent level so that the beneficiaries of the sulfur reduction contribute as well.

Mr. Chairman, I believe that we must develop and use our domestic energy sources, particularly coal. But we cannot do so in a way that destroys our lakes, damages our crops and forests, and poses a threat to human health. We must respond to environmental threats like acid rain promptly and decisively. At the same time, we must do so in an evenhanded and reasonable way. I hope the committee will accept this proposal in that spirit—as a way to proceed without inflicting undue hardship on any one State or region.

I represent a Midwestern State—a coal-producing, coal-burning State. But I want to go halfway—indeed, more than halfway—with you on the question of acid rain. As it stands, S. 1706 imposes an unacceptable level of burden on Missouri, and if put to the test, I could not vote for it. But I think the committee can draft a solution that will meet the need for action and spread the burden of compliance, and I offer this legislation to speed that process along.

Senator **Stafford**. Thank you very much, Senator Danforth. For the committee, we certainly appreciate the thought and effort that you have devoted to this very difficult problem of acid deposition. I have just one or two quick observations and questions on my part.

In your statement you refer to scientific findings suggest that local sources of sulfur dioxide may play a far more important role in the creation of acid deposition than distant sources, my recollection of the testimony on Tuesday was that only two of the nine scientists even suggested that that was in fact true, and that the consensus view was to the contrary.

Then you referred and suggested that the beneficiaries would bear none of the cost under S. 1706 or a bill like it. I have to observe there that currently the States which might be the beneficiaries under something like S. 1706 are now bearing most of the cost since they are the ones who are recipients of acid deposition and they are the ones whose lakes and timber and crops are being damaged as a result of so much sulfur oxides and nitrate oxides getting into the upper atmosphere. I think we have to kind of keep that in mind.

Might I ask you, in connection with the acid deposition trust fund, which is an interesting idea, have you run any studies as to how much money 3 mils per kilowatt-hour sold might generate in the course of a year, or has anybody on your staff?

Senator DANFORTH. I don't know how many dollars, Mr. Chairman, but the projection, as I understand it, of the total cost of the program in S. 1706 is about a 5-percent increase across the whole 31-State region. The effort of this would be to spread that evenly rather than impose a disproportionate amount of the cost on some of the States in the region.

Senator STAFFORD. Your statement is pretty broad in that it says every electric utility. Would you include those utilities that generate by nuclear power and thus aren't part of the problem, at least as far as the atmosphere is concerned?

Senator DANFORTH. Right.

Senator STAFFORD. Would you include all of them?

Senator DANFORTH. Yes.

Senator STAFFORD. Thank you. Again I say this committee is not so hidebound that we don't accept ideas. We appreciate your input.

Senator DANFORTH. Mr. Chairman, if I could just add one point. I was in the Senate Chamber at the time that Senator Mitchell introduced the bill and made his speech introducing it. I immediately joined as a cosponsor because I believe that the problem of acid rain is something which should be viewed as a national problem, not purely a local problem.

We don't suffer from it in Missouri at all, but I think that we in our State cannot be just oblivious to something which is a serious matter in the Eastern and Northeastern part of the country and Canada. It has become an international embarrassment for the United States.

Senator STAFFORD. Indeed it has.

Senator DANFORTH. I think it is something that we should all address and not just by studying it for a few more years.

I think, though, that if we are going to view the matter as a national problem, we have to avoid regionalizing it. The way to regionalize it is to place all the costs on a few States, or virtually all the costs, and give all the benefits to other States. That is the way to fragment the Senate. That is the way to fragment the Congress. Most of the people in the Midwest really would not be willing to have any additional cost in their utility bills for the sake of Vermont or Rhode Island or Maine. But what I am saying is that if we are going to view this as a national problem, then somehow we have to adopt some sort of compromise or rule of reason. That is the principle that underlies the compromise that I am offering today.

It is not a question of what powerplants generate the problem. It is a question of passing legislation to solve the problem. What do we have to do to build a consensus necessary to pass a bill which is going to resolve the problem?

If the only offer that is made is to say well, we will solve it by placing virtually all of the burden on Missouri and a few other States, I don't think that is going to solve it. I think that is just going to hang up the bill.

Senator **Stafford**. Senator, again, we appreciate your proposal, your remarks in support of it, and I personally want to say that I realize it takes considerable political courage for you to do this and make this proposal in a year that is so sensitive for both of us as well as for all four of us in the room.

Senator **Danforth**. All of us.

Senator **Stafford**. So I commend you very highly for putting forward this proposal. I can assure you that this Senator, and I think the committee, will seriously study the proposal that you have made to us.

Senator Mitchell?

Senator **Mitchell**. Thank you, Mr. Chairman.

I join the chairman in commending Senator Danforth for his courage and the commitment he has shown in this area. His statement is a very thoughtful one which I think deserves, and will receive, the careful consideration of the committee.

When I introduced S. 1706, I said then that I did not offer it as the perfect solution, that it was a starting point which ought to receive critical analysis by all of those concerned with the problem—those who favor an immediate solution and those who do not—and that all constructive criticisms would be received in that spirit and carefully studied to see if it can be improved. Many suggestions have in the intervening months been made, some of which I think should be incorporated in the legislation. And I intend to offer a substitute version myself which makes some changes in the bill, responding to the very valid criticisms that have been made by people concerned with this matter. So I take Senator Danforth's statement in that spirit and assure him that I am, and I know the other members of the committee will review it very carefully, thankful for the support he has shown so far in a very difficult situation.

Having said that, I would like to make a couple comments and ask a few questions. Senator, in your statement, you have indicated that after surveying the State's utilities, State air quality officials have estimated the cost of electricity to consumers in Missouri. Are you aware of the assumptions upon which those cost estimates were made?

Senator **Danforth**. No.

Senator **Mitchell**. I would ask you, please, if you could obtain the data upon which that statement is based and submit it to the committee.

I ask that, Senator, for this reason. The bill mandates a total reduction within the acid deposition region described in the bill. It then leaves it, consistent with the framework of the Clean Air Act, entirely to the States and the affected industries to determine the most effective and cost-efficient method of achieving those reductions. The bill sets out several alternative methods of achieving that.

What we have found in connection with previous estimates is that the utility industry has based its estimates of compliance on the most expensive method of compliance and has ignored the possibilities that exist with respect to use of the full range of possibilities. The obvious purpose has been, of course, to arrive at a very high estimate to frighten those who might otherwise want to support the bill into thinking that this will result in dramatic increases in the cost of electricity in their particular States.

So I ask if you would, please, request of the officials the precise and detailed data upon which that estimate is based so we can make a judgment as to its validity. (See p. 254.)

Second, I would comment with respect to the cost of electricity and increases. The National Clean Air Coalition has made an analysis of comparative electricity rates and the effects upon those rates of implementation of this legislation at 10 million tons. It operated on the assumption that not just one method—that is, the installation of scrubbers—would be used and that the full range offered by the bill would be made available.

According to their estimates, by 1990, there would be in Missouri a 7-percent increase in the rate of electricity, the cost of electricity. That would leave the rates in Missouri at that time at 60.23 mils per kilowatt-hour. At the same time, in 1990, the cost of electricity in the three northern New England States to which you referred—Maine, Vermont, and New Hampshire—would be 74.25 mils per kilowatt-hour. That is, even assuming full compliance with Missouri of the 10-million-ton requirement in this bill, the rates of electricity there would be nearly 20 percent lower than they are in northern New England. One of the reasons for that is that the northern New England States and others have already taken steps to control emissions and utilized more expensive, less polluting fuels and other alternative methods.

I make that point leading into a discussion of the second major suggestion, and that is the cost should be borne equally throughout the region. The effect of that, of course, is to impose a double cost upon those who have already taken steps, have paid for, and are at this very moment paying for the cost of cleanup while, of course, reducing significantly the cost of those who have refused to take such steps. I am sure the Senator understands the point that I am making.

Senator DANFORTH. Sure.

Senator MITCHELL. I do not reject the suggestion. I think we ought to consider it. It has not been made in this precise fashion. I think the committee ought to give it serious consideration, because I think what you are pointing out is irrespective of the merits, there is a political problem here, and that is how are we going to get a bill passed? And if we say that those who are dirtying the air have to pay for the cost of cleaning up the air, we are not going to get anything done.

Senator DANFORTH. Senator Mitchell, here is the way I feel about it. As Senator Chafee in particular knows, at the time of the windfall profit tax and the whole issue of decontrolling energy prices and opposing an offsetting tax, one of my concerns was the regionalization of a national issue; that is to say, if there is a change in national policy to solve a problem, you have to be concerned about what the effect of that is going to be and whether it is going to fragment the country.

I joined with you as a cosponsor. I am the only one, I think, in the nonaffected region of the country to join as a cosponsor. You have introduced a bill to change things, to do something. You want Congress to pass a new law, to change the status quo, to do something. In passing the law, it is natural to try to assess the relative costs and benefits from the enactment of that law.

Now, in the bill that you have introduced, there are going to be costs. I don't know whether $100 a person is accurate or not. I know that is one of the assessments. I do know that according to the Office of Technology Assessment, the percentage reduction below the current practice is higher in Missouri than any other State in this region. It is 79.9 percent, as compared with zero in Vermont, zero in Rhode Island, and 16.6 in Maine. So as a result of the bill there is going to be an 80-percent reduction in my State of Missouri. That is the cost. The benefit in Missouri is zero.

So in a single bill, just trying to weigh the costs and the benefits, it is a little bit difficult, I think, to say to one part of the country, "All right, here is some new legislation, and your benefit is going to be zero and your cost is going to be higher than any other State in the Union."

Senator **Mitchell**. Could I just comment on that, Senator? Now I agree completely with you, that the cost should be borne by those receiving the benefit. I do not agree that my bill imposes a new cost.

At this very moment, a cost is being paid for the failure to control sulfur dioxide emissions in this country. The cost is being paid in the death of bodies of water in northern New England. The cost is being borne in the loss of Atlantic salmon in parts of the Eastern part of the United States and in Canada.

Now, that is not as easy a cost to assess as the cost of installing a piece of equipment in a utility plant in Missouri. But it is a real cost in our society.

I am sure the Senator would agree there is some value, difficult to assign, nonetheless there is a value in having a trout pond in northern Maine die or a salmon river in eastern Canada die. So the point is a cost is now being borne, and it is not being borne by those who are deriving the benefit. The benefit of the low cost of electricity, because of the lack of adequate pollution control, is being achieved by the people of Missouri and Illinois and Ohio at the expense of the people of New York, Vermont, and Maine whose waters are being destroyed. And the purpose of my bill is to do precisely what you have suggested should be done; that is, to allocate the cost to those who are bearing the benefit.

Now, you have in your usual incisive fashion struck at the heart of the issue: How do you achieve this allocation in a fair manner and one which is likely to achieve support in the Congress to get something done? So I don't think we disagree at all in objectives. But the point I want to make is that there is a cost being borne at this very moment.

Senator **Danforth**. Senator, I am a cosponsor of your bill.

Senator **Mitchell**. I know that. I thank you for that. I also know, as you said at the end, you wouldn't vote for it.

Senator **Danforth**. That is right. I am a cosponsor of your bill because I want to fix something. I want to fix something that has to be fixed. I don't want to wait around. I want to get a bill passed. But when a Senator goes out on the floor of the Senate, there are only two words that he can say, aye or no. There is no other option for him.

Senator **Mitchell**. We hope we can make it possible for you to make it aye.

Senator **Danforth**. If you are going to get enough people to say aye, in order to pass some legislation, you can't very well, I don't think, ask a Senator to go out on the floor and vote for a massive increase in the utility bills for his constituents with no benefits to show. I think that you can say, "look, we are going to have to have some changes. It is a national problem. You are going to have to bear a share of fixing it." But I don't think you can say, "You are going to have the greatest share of fixing it and none of the benefits."

Senator **Stafford**. If the Chair might intercede just a moment, if all we could say on the floor of the Senate was aye or no, it would eliminate a lot of filibusters and a lot of other speeches being made over there.

Senator **Mitchell**. I know my time is up. Let me just conclude by saying that we hope very much—firstoff, let me assure you there will be changes, because there have been valid criticisms made that ought to be included in the bill. Second, we hope that the changes will be sufficient to induce you to continue your consistent courage and support so far.

Senator **Stafford**. Senator Chafee?

Senator **Chafee**. Thank you.

I want to commend Senator Danforth for his appearance here today and for the position he took in connection with this legislation. I believe he said he thought he was the only one from the area where the cost are going to be incurred under this legislation—to cosponsor this legislation. I am confident he is right. His career here has been marked by courage. I hope that courage isn't too costly to him.

Senator **Danforth**. I couldn't agree more, Senator.

Senator **Chafee**. I know that the major issues in Missouri continue to be the Panama Canal.

Senator **Stafford**. In that they have a lot of company.

Senator **Chafee**. The points you made are very valid ones. It seems to me that, not setting aside anything you say, we do have a terrible problem here in that, as Senator Mitchell pointed out, we have one section of the country that is benefiting. That is, they are burning high-sulfur, low-cost coal, which permits them to have low rates, and thus, presumably more competitive industry. And as a result of their doing this, the States that are downwind are having their lakes, forests, and fields polluted.

When a national problem comes up such as that, and national problems have been addressed in flooding rivers and in tornadoes and volcanoes and a whole series of things, then the Nation responds. The Northeast, in the days when we were the wealthy section of the country, responded very, very generously through a whole series of measures to help other parts of the country. I think of particularly TVA, where now they are blessed with very low power as a result of massive funds poured in there from all over. But the Northeast proportionately, I am confident, was a larger contributor than other sections.

At the same time, we have a situation where we are paying higher costs for our electricity because we are producing less sulfur. We are not an offender. It isn't just that ours blows out to the ocean somewhere, which is the only area downwind from us, but that we are burning low-sulfur, expensive coal. So we are, whether it is the local pollution or long-range pollution, not an offender to the degree that the States that are upwind from us are.

In any event, we appreciate your coming here. You have given us a lot to think about. As always, you have made a real contribution. Thank you.

Senator **Danforth**. Thank you, Senator.

Senator **Stafford**. Thank you, Senator Chafee.

Thank you, Senator Danforth.

Senator **Danforth**. Mr. Chairman, thank you.

Senator **Stafford**. We would be glad to have you stay here, but we assume you have other serious duties. Again, we admire your courage and appreciate your contributions.

We have a panel that we would like to go ahead with, with the caveat that if Senator Byrd is able to be with us, we may interrupt the panel long enough for him to testify. The panel consists of Dr. Ellis Cowling, Dr. Robert Lackey, Dr. Noye Johnson, Dr. Joan Baker, Dr. Lance Evans, Dr. Arthur Johnson, Dr. Dale Johnson, and Dr. Orie Loucks. We would invite the panel to come to the witness table.

The Chair's intent would be to ask the witnesses to testify in the order in which I announced their presence. I see that is the order in which they are pretty much lined up.

We would ask that witnesses summarize their testimony in 5 minutes, if possible, in view of the numbers, and statements that have been delivered to the committee will be placed in the record in full so that they will be available for the entire committee to study, along with professional staff members representing each member of the committee.

That being the case, the first member of the panel to testify will be Dr. Ellis Cowling, associate dean for research, School of Forest Resources, assistant director, North Carolina Agricultural Research Service, North Carolina State University, Raleigh, N.C.

Dr. Cowling?

STATEMENTS OF ELLIS B. COWLING, ASSOCIATE DEAN FOR RESEARCH, SCHOOL OF FOREST RESOURCES, ASSISTANT DIRECTOR, NORTH CAROLINA AGRICULTURAL RESEARCH SERVICE, NORTH CAROLINA STATE UNIVERSITY, RALEIGH, N.C.; ROBERT T. LACKEY, SENIOR ECOLOGIST, ENVIRONMENTAL RESEARCH LABORATORY, ENVIRONMENTAL PROTECTION AGENCY, CORVALLIS, OREG.; NOYE JOHNSON, PROFESSOR OF GEOLOGY, EARTH SCIENCES DEPARTMENT, DARTMOUTH COLLEGE, HANOVER, N.H.; JOAN P. BAKER, ASSISTANT PROFESSOR/RESEARCH ASSOCIATE, SCHOOL OF FORESTRY AND ENVIRONMENTAL STUDIES, DUKE UNIVERSITY, DURHAM, N.C.; LANCE EVANS, ASSOCIATE PROFESSOR OF BIOLOGY, LABORATORY OF PLANT MORPHOGENESIS, MANHATTAN COLLEGE, THE BRONX, N.Y.; ARTHUR JOHNSON, ASSOCIATE PROFESSOR (SOILS), UNIVERSITY OF PENNSYLVANIA, PHILADELPHIA, PA.; DALE W. JOHNSON, RESEARCH STAFF MEMBER, ENVIRONMENTAL SCIENCES DIVISION, OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TENN.; AND ORIE L. LOUCKS, SCIENCE DIRECTOR, THE INSTITUTE OF ECOLOGY, BUTLER UNIVERSITY, INDIANAPOLIS, IND.

Dr. COWLING. Thank you, Senator Stafford. I will try to use a few slides to illustrate certain portions of my remarks.

Senator STAFFORD. I should caution the panelists that our mikes don't seem to be all that strong today. If you could, please, speak fairly closely into them.

Dr. COWLING. I will speak up. Thank you.

Since 1976, I have been privileged to lead a group of scientists in this country who have formed what is called the National Atmospheric Deposition program. The first slide shows some of the locations in which the scientists affiliated with this program have been working to provide an understanding of the chemistry of atmospheric deposition and to do research on the effects of acid deposition in particular.

The second slide this morning shows that acid precipitation is occurring in very large regions across the North American Continent. The areas receiving highly acid precipitation—that is, with an average annual hydrogen-ion concentration between 4.1 and 4.6—include many regions in which surface waters and aquatic life are sensitive to or are presently being affected by acid precipitation.

This slide shows the zone receiving acid deposition circled by the line marked 4.6.

Senator STAFFORD. Doctor, might I interrupt just a minute. That seems to include most of the eastern half of the United States and the eastern third of Canada, does it not?

Dr. COWLING. That is correct. About two-thirds of the total land area of North America now receives acid deposition.

Senator STAFFORD. It appears to me, if my geography is right and my eyesight hasn't failed, that Missouri seems to be within the area.

Dr. COWLING. I will look at the map again, but I think you are correct, sir.

The next slide shows the regions in the United States and Canada where important biological effects have been observed. That is what the stars mean.

It is interesting to observe the coincidence here between the zone that is receiving acid deposition and is sensitive, shown by the shaded areas, and the areas where damage has actually been reported. I am speaking of biologically important harm to aquatic ecosystems. I am not speaking about forests.

In general, I would like to summarize by saying much more is known at present about the nature, the geographical location and the extent of detrimental effects of acid deposition on fish and other aquatic life and drinking water quality than about possible effects on agricultural crops and forests. I think my fellow panelists will verify that statement today.

I said a year ago in a publication of the National Research Council that "The effects of acid precipitation and associated metal ion toxicity on aquatic ecosystems are sufficient to warrant preliminary formulation of management and ameliorative strategies." I further said, "The potential effects of acid precipitation on terrestrial organisms are not understood well enough to justify consideration of management strategies at this time," which was late 1980.

Senator CHAFEE. Could you just repeat that? What page are you on?

Dr. COWLING. I am on page 7.

Senator CHAFEE. Could you just repeat that statement you made, the last statement, please, Doctor?

Dr. COWLING. "The effects of acid precipitation and associated metal ion toxicity on aquatic ecosystems are sufficient to warrant preliminary formulation of management and ameliorative strategies, but the potential effects of acid precipitation on terrestrial organisms are not understood well enough to justify consideration of management strategies" based on harm to forests or agriculture, "at this time."

Senator CHAFEE. I was going to say could you explain what that means, but let me try it another way. Could you rephrase that?

Dr. COWLING. Sure. The effects of acid deposition on an aquatic ecosystem are well demonstrated. The effects of acid deposition on forests and agricultural systems are yet ambiguous so that it is not possible to generalize that there are more harmful effects of acid deposition than beneficial effects on either forests or agriculture.

Senator CHAFEE. But going back to your prior statement, "The effects of acid precipitation and associated metal ion toxicity on aquatic ecosystems are sufficient to warrant preliminary formulation of management and ameliorative strategies," in other words, we know enough about it that it warrants we do something about it?

Dr. COWLING. That is my scientific judgment.

Senator CHAFEE. On aquatic ecosystems. But we don't know enough about the terrestrial organisms?

Dr. COWLING. That is correct.

Senator CHAFEE. The land and the forests.

Dr. COWLING. That is exactly right.

Senator CHAFEE. Thank you.

Senator **Stafford**. Thank you. I thought maybe I should observe now, since I made an earlier observation about the areas covered by acid precipitation deposition, that the areas this chart shows have been shown to have damage do not include the State of Missouri.

Dr. **Cowling**. Yes; that is correct.

Senator **Stafford**. All right.

Senator **Chafee**. Also, it is curious that it goes inland. It looks like Georgia and North Carolina, and up into Virginia, but it comes down in a peculiar place but does not go all the way to the coast.

Dr. **Cowling**. Yes; I am not sure that that squiggle in the line is a dependable thing that would show up every year. I should emphasize the data upon which this particular graph are drawn is 1979. We now have the current data for 1980. We will look at that in a minute.

The general deposition pattern, this very large area of eastern North America receiving acid deposition and the definition of sensitive region so far as aquatic ecosystems are concerned, I think that is widely accepted. But the squiggle in the line with regard to eastern North Carolina, I am not sure that is something that would be dependable.

Senator **Stafford**. I guess we have to move ahead. We have already used up 5 minutes.

Dr. **Cowling**. Would you prefer if I stopped here?

Senator **Stafford**. No; go ahead. I don't want to stop you.

Dr. **Cowling**. Let me take the microphone and move through the slides quickly and make one very brief statement. The next slide, please.

This shows the regions fron which the acid-producing emissions come. This is a map of the sources of nitrogen oxide emissions.

The next slide shows the conventional wisdom about how the winds blow in North America. It starts in the north and goes to the east and ends up usually over the St. Lawrence River. This is a conventional wisdom which is untrue.

The next slide shows something more near what really happens. That is, the wind blows in a great many ways in North America. I think that this should be understood. There are times when emissions in New England affect Florida. There are times when emissions in Missouri affect North Carolina. There are times when emissions in North Carolina affect Minnesota. There are times when Louisiana emissions would affect Vermont.

The next slide is related to the matters that you heard in the testimony 2 days ago. I am afraid we have a technological difficulty here.

Senator **Stafford**. This used to happen in the Navy in World War II.

Dr. **Cowling**. It says in the hearing record that you had 2 days ago that there was a net movement of the emissions from a zone of emission to a zone of deposition, and that is correct. But it is important to realize that the direction of that movement is not unilateral. It sometimes goes west, sometimes south, sometimes north, sometimes east. The net displacement is slightly to the east and slightly to the north. But the emissions in this vast region of emissions, which includes the whole of the industrial regions of eastern North America, affect the whole of eastern North America.

You notice that the zone you just saw is roughly symmetrical in shape.

Senator **STAFFORD**. Yes.

Dr. **COWLING**. The next slide. Here is the zone of emissions of sulfur dioxides. This includes all of the area of the eastern United States and southeastern Canada. If we now look at the 1980 deposition record, and Mr. Chafee, I think you will see that this squiggle in the line over North Carolina is missing—next slide, please. No, excuse me. I am mixed up on the slides.

This shows the areas again that are sensitive. In order to protect those sensitive regions, and particularly the Appalachian Mountain chains—we hear a lot of discussion in the press and in the scientific literature also about effects in the Adirondacks and in southeastern Canada. But we should understand that there also are effects along the Appalachian Mountain chains and that fish kills in North Carolina have now occurred 2 years in a row. So acid deposition is having pronounced effects on water quality and on fish life not only in New England but also in the Southeastern United States.

If we desire to protect these sensitive resources, it appears, considering the distance that the air travels, and the time that sulfur and nitrogen oxides remain aloft, that if we choose to protect those sensitive resources by decreasing emissions, that it will be necessary to undertake a general decrease in emissions. And if we can go back one slide. That means decreasing emissions in most of the industrial regions of eastern North America.

I would simply conclude with the remark that is made on page 12 of my testimony. That is if we were to undertake today to make a decision with regard to this pathway of protection of our aquatic resources, I think it is important to realize that it would take about 5 years to select the methodology by which each State or Province in eastern North America could make its contribution, and that we would expect that it would take another 5 years, if a decision were reached in this year, before significant decreases in deposition would be achieved in these sensitive regions.

Therefore, it seems to me prudent that we should now begin in earnest a debate in both the United States and Canada about how, in each of our contributing States and provinces, we would undertake to achieve the necessary reductions in emissions that would be required.

Thank you very much.

Senator **STAFFORD**. Thank you very much, Dr. Cowling.

The next witness will not be in the order in which you are seated but the order in which you are listed on our witness list. Dr. Robert T. Lackey will be the next witness. He is a Senior Ecologist, Environmental Research Laboratory, Environmental Protection Agency in Oregon. He will be followed by Dr. Noye Johnson. He will be followed by Dr. Joan P. Baker. So that you will have the batting order here in advance.

Dr. Lackey?

STATEMENT OF ROBERT T. LACKEY

Dr. LACKEY. Yes. Thank you very much.

I would like to first make a comment that I am here as an aquatic scientist. My training is in the areas of fisheries and aquatic biology. I am also very heavily involved in a research program that EPA has undertaken in conjunction with other Federal agencies. Let me highlight just a few comments from my prepared material.

EPA has conducted research relating to the aquatic and natural terrestrial effects of acid deposition for a number of years. Our activities have stemmed from a broader concern over the potential adverse impact of acid deposition on crops, forests, and their supporting soils, fish, and other aquatic life, and we are also concerned with water quality in general, particularly drinking water. For many of the lakes and streams in the United States and Canada, water quality is intimately linked with the process of forested watersheds. Other speakers on this panel will address that particular issue.

While a great deal has been learned to date regarding these types of effects, as Dr. Cowling has accurately pointed out, there also needs to be much additional information understood before we have an accurate assessment of the extent of the problems.

The major uncertainties we are concerned with exist in the areas related to the effects on growth and yield of forests as well as the effects on rate of lake acidification and the number of lakes at risk to acidification nationally. It is toward these aims and other uncertainties that our current efforts are aimed.

Just briefly, let me talk about some of the research that is ongoing both within EPA and within other Federal agencies concerned with this problem.

Over the next 3 to 5 years, we expect to gain knowledge in these areas from a number of our research efforts. These include the following.

There are five major theme areas in the aquatic effects arena.

Quantify—and I stress the word quantity—the extent of acidification and the sensitivity of lakes, streams, and groundwater in the United States through the assembly of a national inventory and additional field supporting studies.

Second, to identify and quantify the factors which control the tolerance, sensitivity and susceptibility of surface waters and groundwater to acidification through studies of snow melts and watersheds and through development and use of acidification models.

Third, identify and quantify the effects of surface water acidification on biological processes and populations through studies on fish and fisheries and wetlands effects and wildlife.

A fourth major area, assess the potential effects of acid precipitation on drinking water quality through completion of a survey of present and historical drinking water quality in New York and New England.

A fifth major area of research, develop mitigation strategies for restoring or protecting acidified lakes and streams and conduct liming studies of lakes, streams, and limestone filtration of drinking water.

Just briefly I want to talk about two of our research areas. These are done in different parts by different laboratories within the agencies.

A major objective of our effort is the quantification and determination of changes in the quality of surface and groundwater caused by acid precipitation. We are now conducting a quantitative national assessment of the extent and magnitude of the problem.

A program has been implemented first by a national inventory to bring together on a State-by-State basis—and I stress this is a national program—relevant water quality data already in existence, and to apply these data in various ways to assess the problem. This program is led by my laboratory, which is in Oregon, and includes a number of other Federal agencies and national laboratories. These include the Fish and Wildlife Service, Forest Service, Geological Survey, Tennessee Valley Authority, Brookhaven National Lab, and some others.

The objectives of this program are to:

(1) Identify and map the extent and degree of acidification and sensitivity to acidification of lakes and streams in the United States;

(2) determine trends in the acidification of surface waters;

(3) provide a verified , quality-assured data base to:

(a) Apply available methodologies to predict surface water acidification based on given deposition rates, and

(b) relate patterns of surface water sensitivity with spatial patterns of climactic, physical, and land-use factors.

A second major objective carried out under our program is the identification and quantification of the factors which control the tolerance, sensitivity and susceptibility of surface and groundwaters to acidification. My prepared statement goes into more detail on this topic, but I will just say briefly this is carried out by the Duluth Laboratory of that agency. It is working with 30 lakes and 5 calibrated watersheds. This research is ongoing and should be completed within a year or two.

I think I will stop there, Mr. Chairman, and the more detailed comments are in the prepared text.

Senator STAFFORD. Thank you very much. We appreciate your accomplishing it within the 5-minute time frame.

Senator MITCHELL. Mr. Chairman, is it your desire that we permit all the witnesses to complete their statements before questioning, as we did Tuesday?

Senator STAFFORD. That is what I would like to do, if it is agreeable.

Senator MITCHELL. I have no objection. I just have some questions of this witness and I wanted to know when the proper time to ask them was.

Senator STAFFORD. I had some of Dr. Cowling, which I decided to put off until we got through. So we will go through the witnesses as rapidly as we can, giving them a reasonable chance to present summaries of their statements.

I notice, Dr. Johnson, you are a professor of geology, Earth Sciences Department, Dartmouth College, Hanover, N.H., which isn't very far from where I live in Vermont.

STATEMENT OF NOYE M. JOHNSON

Dr. **Noye Johnson**. Mr. Chairman, I appreciate the opportunity to present you with some specific evidence regarding the effects of acid rain in New England. In the few moments I have here I hope to introduce you to the data and some of the implications behind these data. My main purpose is to explain why acid rain has such a powerful leverage on some chemical systems.

First let me say I'm speaking on behalf of a whole group of scientists, loosely associated in a study known as the Hubbard Brook study, which has been monitoring acid rain and studying its effects since 1964. In fact, the first explicit reports of acid rain in North America in 1972 were based on the data from the Hubbard Brook study. Some 500 scientific papers have been published out of the Hubbard Brook study during the past two decade. I say this just to emphasize that what I present here is not just anecdotal in scope or an opinion, but is based rather on hard data reaching back some 28 years.

The first feature of the acid rain phenomenon I want to mention concerns its qualitative nature. It is usually surprising to find that the amount of acidity deposited over a landscape from contemporary acid rain is not really exceptional; however, the intensity of the acidity from time-to-time truly is exceptional. Contemporary acid rain comes in brief burst of concentrated acidity, interspersed with long intervals with little or no acid deposition at all. This is in marked contrast to natural rainfall and carbonated waters where acidity can be continuously replenished at any time by the absorption of atmospheric carbon dioxide. The net result is that present acid rain exposes the landscape to short bursts of high acid concentration, but that over the longer term the amount of total acid deposition is not especially high.

The second item I want to bring to your attention is related to the first. It is well established by theory and observation that the solubility of most materials is controlled by acid concentration. Not acid amount, acid flux or acid rain per se, but acid concentration. Standard practice in chemistry takes this into account by measuring a material's solubility under specified conditions of acid concentration. The solubility of some natural materials is enormously sensitive to acid concentration. A relevant example is the solubility of the common Earth material, aluminum. By way of example, increasing acid concentration by 10 percent elicits a 33-percent increase in aluminum solubility. If you should double acid concentration, however, aluminum solubility increases 800 percent. If you should increase acid concentration by ten fold, a in the case with acid rain, aluminum solubility increases by a 1,000-fold, or 100,000 percent. I use these figures to illustrate the extraordinary leverage that acid concentration has on the solubility of some common natural materials. It follows then that acid rain, by increasing local acid concentraton, however briefly, has a powerful effect on dissolving any aluminum salts that happen to be exposed. In many cases increasing acid concentration acts not linearly, but geometrically with regard to chemical effect. High acid concentration enables reactions to take place that otherwise would not take place.

Finally, it should not be surprising therefore that in our studies at Hubbard Brook (Johnson, et al., 1981) and elsewhere in the Northeast (Driscoll, 1980 Parnell, 1982) we have found that soil aluminum is being dissolved at the present time by acid rain. We have abundant documentation to show that aluminum is being moved out of soil zones where it used to be naturally deposited, and that aluminum is being moved into soil zones where ordinarily it would to be (Parnell, 1982). This translocation of soil aluminum is the direct consequence of the strong acids present in contemporary acid rain and not the normal acids associated with the soil. Some of the soil aluminum which has taken into solution is leaking downstream into rivers and lakes where it didn't used to be. The biologic consequences if this aluminum presence in lakes and streams will be addessed by Dr. Joan Baker at this hearing.

In summary, a large body of hard data exists that shows that over large reaches of the Northeast, involving tens of thousands of square miles, soil aluminum is being mobilized and redistributed because of the present intensity of acid rain. This chemical effect is explained by simple, fundamental principles of chemistry. That is, because acid rain provides episodes of high acid concentration from time to time, chemical reactions that ordinarily couldn't take place, are taking place. The present mobility of soil aluminum over the Northeast exemplifies this effect.

The essential point here is that for the past 10,000 years or so the soil zone over New England has been a stable repository for aluminum. Today, because of the increased intensity of acid rain, this situation has been dramatically changed. The effect is quite subtle, but it is real. It nicely illustrates how anthropogenic actions is one place on Earth can cause surprising and unintended reactions elsewhere.

The leverage effect of acid rain on certain chemical reactions also has an important bearing on emissions control. The leverage effect, as it was discussed previously, cuts both ways. For a specific case in point, increasing the acid concentration of rain a little bit, increases the mobility of soil aluminum a great deal. Conversely, reducing the acid concentration of rain a little bit, reduces the mobility of soil aluminum a greal deal. This logic thus suggests that the first increment of acidity removed from acid rain stands to make the biggest difference. Each successive increment of acidity removed will be harder and more expensive to do, and will produce less results than the first. In my opinion then, as a scientist and citizen, it would be prudent to arrest any further increases in acid emissions to the atmosphere, and also to take steps to reduce the level of present emissions. To do otherwise would be quite shortsighted, given the clues and signs that nature is loudly broadcasting to us at the present time. Thank you.

[An attachment to Dr. Noye Johnson's statement follows:]

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Brook Experimental Forest, New Hampshire, Geochim. Cosmochin Acta, 45, 9, 1421-1437.

Parnell, R. A. (1982) Aluminum Migration and Chemical Weathering in Subalpine and Alpine Soils and Tills, Mt. Moosilauke, N.H.: The Effects of Acid Rain, Dartmouth College Library, Hanover, N.H.

Senator STAFFORD. Now we will be very pleased to hear from Dr. Joan Baker, assistant professor/research associate, School of Forestry and Environmental Studies, Duke University, Durham, N.C.

STATEMENT OF JOAN P. BAKER

Dr. BAKER. Thank you, Mr. Chairman. It is my belief that acidic deposition has resulted in the acidification of a large number of susceptible surface waters in areas of the Northeastern United States, Eastern Canada, and perhaps elsewhere. As a result of this acidification, biological communities in impacted lakes and streams are being altered.

The best evidence for these responses comes not from any one particular area or one particular study, none of which by themselves may be 100 percent convincing or complete, but instead from the total mass of evidence being accumulated by American, Canadian, and Scandinavian researchers.

Unfortunately, in 5 minutes I cannot come close to even summarizing the key points of this work. Therefore, my testimony will focus on only one area, the Adirondack region of New York, the most severely impacted area in the United States today and also the area where I personally conducted my research.

In 1975, high elevation lakes in the Adirondacks were surveyed and 52 percent of these lakes were found to be very acidic, with pHs below 5.0. This data and data collected in years since then have indicated an unexpectedly large number of acid lakes in the Adirondacks. The key question is, is this relatively large number of acid lakes a result of acidic deposition? Alternatively, many of these acid lakes may have always been acidic due to natural organic acids, or the acidic conditions may have resulted from human disturbances other than the long-range transport of air pollutants.

To address the first point, ideally we need historical records of past pH levels in acidic lakes. For a small fraction of the lakes in the Adirondacks we have such data—pH measurements made by the New York State Department of Environmental Conservation in the 1930's.

Now, within a subset of lakes with historical pH data, in 1975, 47 percent of these lakes were very acidic, with pH levels below 5.0, and 52 percent had no fish. On the other hand, in the 1930's, only 7 percent of these lakes had pH levels below 5.0 and only 10 percent had no fish.

Similar changes in acidity have been documented for lakes in other areas of the Adirondacks, New England, and other regions of the world. Together they form conclusive evidence of the ongoing acidification of surface waters.

It is true that some of the acid lakes in the Adirondacks are acid primarily due to natural organic acids and may have always been acid. But this natural acid source cannot account for the increasingly large number of acid lakes in the Adirondacks today. The question of the role of human disturbances, other than long-range transport of air pollutants—for example, logging—has not been directly addressed for Adirondack lakes. Note, however, that the most acid lakes in the Adirondacks—that is, the high elevation lakes—are also the most remote from logging and other human disturbances. Also recall that other regions, such as northern Wisconsin and southwestern Ontario, have also been heavily logged and yet acidification of susceptible surface waters has not occurred. These areas also do not receive high levels of acidic deposition.

Certainly in some instances natural organic acids and/or land use changes may play a role in acidification of a specific lake or stream. However, they cannot explain the widespread and consistent acidification of sensitive lakes and streams receiving acidic deposition.

Increased acidity has an impact on biological communities. My discussion will focus on fish since my research has focused on fish.

As was previously mentioned, in the 1975 survey, 52 percent of the high elevation lakes in the Adirondacks were very acidic. Of these, 81 percent had no fish. In contrast, of the lakes with pH levels above 5.0, only 1 percent had no fish. Now, again, it is possible that some of these acidic lakes and streams never had any fish. However, it is also definite that many lakes and streams in the Adirondacks, according to historical records, previously sustained fish either through natural reproduction or stocking and now will not sustain fish either through natural reproduction or stocking.

The New York State Department of Environmental Conservation estimates that at least 180 lakes that previously had brook trout populations are now devoid of brook trout.

Historical data on specific lakes can also be examined in detail. For example, I have worked on South Lake in the Adirondacks. It is a fairly large and accessible lake, and South Lake was extensively stocked with brook trout and/or lake trout at various times from the 1930's up until 1978. Netting surveys by the State indicated that in the 1950's and 1960's trout were common in the lake. Fishing quality declined in the 1970's, and extensive survey netting from 1973 to 1975 yielded few lake trout and brook trout and in 1976 and 1978 no fish at all were collected. In 1979, South Lake had a pH of 4.9 to 5.0. Records of fish population status in a number of other Adirondack lakes reveal similar trends.

Now the final approach to examining the effects of acidification on fish is to confirm experimentally that acidic conditions can kill fish. In 1977 and 1978, we sampled three Adirondack lakes and their tributaries. From this and other studies it was established that elevated aluminum levels are associated with acidic conditions. Then in a series of laboratory studies from 1977 to 1979 with young brook trout and young white suckers we found that pH and aluminum levels, within the range of those measured in the Adirondack lakes and streams, were found to be acutely toxic to fish and also to reduce fish growth. In addition, young fish were exposed to acidic Adirondack lake and stream water in the laboratory and survival and growth monitored. In each instance, survival and growth were clearly correlated with pH level and inorganic aluminum concentration. These laboratory data provide strong support for the hypothesis that the low pH level and high aluminum concentrations, resulting from acidification of surface waters, are responsible for the observed declines in fish populations in impacted waters in the Northeastern United States, eastern Canada, and southern Scandinavia.

Thank you.

Senator **Stafford.** Thank you very much, Dr. Baker. The Chair is particularly grateful to you. You have provided a scientific basis for my failure to catch any fish in many of those lakes.

The next witness will be Dr. Evans, to be followed by Dr. Arthur Johnson. Dr. Lance Evans is associate professor of biology, Laboratory of Plant Morphogenesis, Manhattan College, the Bronx, N.Y.

Dr. Evans?

STATEMENT OF LANCE S. EVANS

Dr. **Evans.** Thank you, Mr. Chairman.

For several years we have been interested in the effects that acid rain may have on crop plants. Our studies originated at Brookhaven National Laboratory on Long Island in the fall of 1975. Many other research groups in the United States have also been looking at the effects of acid rain on crops, and I would like to give you a brief overview of what we think the situation is.

Our first approach was to do greenhouse-type studies in which we looked at plant foilage to survey what kinds of chemicals might be absorbed by foilage, what kinds of chemicals might be leached by foilage, and to get a matched balance reaction as to those kinds of considerations.

Research at Oak Ridge National Laboratory has suggested that for crop plants most of the effects of acidic deposition probably would occur on the foliage. We made the same sorts of conclusions about the same time.

Since 1978 we have been conducting field studies in the agricultural fields at Brookhaven National Laboratory. That is essentially 4 years of field data. In our latest study, we constructed exclusion chambers which are, in English units, 30 feet wide, and each of these units was 96 feet long. We had two of them, so that we could exclude ambient rainfalls from hitting the soybean crops. Soybeans are an important crop in the United States, as you know, and the annual return to soybean growers is approximately $14.6 billion in 1979 dollars.

We chose soybeans because previous experiments suggested that the foilage of soybeans was particularly sensitive to our simulated rainfall solutions.

Under standard agricultural procedures, we administered the simulated acid rain at four different pH levels: pH 5.6, which is unpolluted rain; pH 4.1, which is very similar to the pH of rainfall that occurs on Long Island during the growing season—that is from data from the last three summers—and we also used pH 3.3 and pH 2.7. Rainfalls of pH 3.3 occur on Long Island and they comprise about 7 percent of the rainfalls during the growing season. On Long Island, pH 2.7 rainfalls do not occur, but we used that low rainfall to try to generate a dose response function test for the effects on soybeans.

Compared with the pH 5.6 control, we demonstrated decreases in soybean yields of 10.7 percent, 16.8 percent, and 22.9 percent for plants receiving simulated rainfalls of pH 4.1, 3.3, and 2.7 respectively.

It is interesting to note that the yield of plants that were grown out-of-doors—that is, not under our shielded rainfall regime—had yields that were very similar, 11.7 grams per plant, to those that received the simulated rainfalls underneath our exclusion plot apparatus. In addition, our yields of beans are similar to yields obtained in the major soybean growing areas of the United States. There is no reason to suspect that different results would be obtained elsewhere.

These changes in seed yields are statistically significant, as determined by analysis of variants, and we think that these kinds of studies need to be done again this summer and need to be done again in other locations of the United States with other crop plants to assess what the effects of ambient levels of acid rain might have on crops.

In summary, although we have about 4 to 5 to 6 years' worth of data, on the effects of simulated acid rain on crop plants, we have some indications that certain species are being affected by acid rain and that more research is necessary to come to grips with what the situation might be for other crops.

My remarks as far as describing this experiment and describing the overall philosophy as to how acidic deposition might affect crop tests are in the written statement. I will refer the written statement to you.

Thank you very much.

Senator **Stafford**. Thank you very much, Dr. Evans. The next witness will be Dr. Arthur Johnson. He will be followed by Dr. Dale Johnson. I think the Johnson's have everybody else outnumbered here this morning.

Dr. Arthur Johnson is associate professor for Soils, University of Pennsylvania, Philadelphia, Pa. Dr. Johnson?

STATEMENT OF ARTHUR H. JOHNSON

Dr. **Arthur Johnson**. Thank you, Mr. Chairman. I would like to begin by telling you that I am a Vermont taxpayer and a summer and winter resident of the Camel Sump area.

Senator **Stafford**. I better see you after we break.

Dr. **Arthur Johnson**. Perhaps a little bit more relevant, my training and research have been primarily in the fields of soil chemistry and the bio-geo-chemistry of forest ecosystems. My statements today concern the status of research on acid deposition on forest growth.

Determining what effect acid deposition has had or will have on forests, involves understanding the direct effects on plant tissue and the effects on soil properties which may in turn affect plant growth. Although some soils in some areas may develop acidity over time as a result of acid deposition, we are not presently confronting a situation of substantial anthropogenic alteration of pH in forest soils. Additionally, we do not see acute toxic effects on plants at ambient precipitation pH levels. Thus, we are trying to assess the possibility of subtle chronic effects.

There are relevant results to report from experimental studies and empirical studies. The evidence from experimental work indicates that acid deposition can have direct or indirect effects on vegetation, and that these effects may be positive or negative. The sum of the experimental work indicates that acid deposition at current ambient levels can have effects that might cause reduced growth in forests. There are also some results which indicate that acid deposition can stimulate growth at least in the short run.

It is difficult to extrapolate the experimental results to confidently say what acid deposition is actually doing in forests, primarily because the experimental conditions were simplified relative to those which prevail in natural forests. Thus, assessment of what has happened to forest growth over the past 30 years becomes an important consideration.

Several empirical studies of tree growth and health have been carried out in North America and Europe. A decade-long study of Norway spruce in Germany suggests that acid loading by ambient precipitation has increased soil aluminum mobility, increased aluminum uptake by roots to toxic levels, caused root dieback, and subsequent death to susceptible trees.

The circumstantial evidence for this chain of acid deposition induced events is sound, but experimental confirmation is lacking. Several investigators have used historical patterns of tree rings, data on climate, and other environmental parameters and regional or historical patterns of acid deposition to determine if acid deposition could be affecting tree growth.

Several studies have been done in North America, Sweden, and Norway which indicate that growth rates have been less than expected for the past 20 to 30 years. The methods by which investigators sought to determine if acid deposition was an important factor varied, but the evidence leaves acid deposition as a possible cause in all cases.

No one has reported growth rate increases in natural, unmanaged forest stands which are coincident with spatial or temporal patterns of acid deposition.

I have been personally involved in studies of soil, water, and vegetation in New England and in New Jersey, and the results of that research can be summarized as follows. Widespread, substantial, and sustained decreases in growth rate which began during the last two or three decades have been observed in pitch pine and shortleaf pine in southern New Jersey and in red spruce in high elevation stands in Vermont and New Hampshire. I wish to emphasize the widespread, substantial, and sustained portion of that.

In southern New Jersey substantial records of historical stream pH indicate that streams in the region became increasingly acidic between 1960 and 1980. Correlations among stream pH, precipitation pH, climactic data, air quality data, and tree growth suggested acid deposition is a stress related to the growth rate decline.

In addition to reduced growth in the Green Mountains of Vermont, a dieback of red spruce has been quantitatively documented and substantial spruce mortality is visible in New Hampshire, New York and Connecticut. In the high elevation forests of Green Mountains of Vermont, approximately 50 percent of the red spruce have died over the past 15 years. Work to date on pathogens, climate, fog and rain chemistry, foliar chemistry, root chemistry, patterns of tree rings, and the relationship of tree rings to climate and air quality data indicate that acid deposition is a plausible contributing stress in the spruce dieback phenomenon. At present there are very few clues which point to any other mechanisms.

So what we know is that unfavorable changes in tree growth occurred after 1950 in Europe and North America. At present the causes are unknown. But the reduction in growth and mortality cannot be attributed to climatic changes or to any other obvious factors. Acid deposition is a plausible cause or contributing stress and has been implicated in some cases by statistical evidence.

Given that we cannot confidently determine what acid rain is actually doing to tree growth at present, we have little basis for predicting what may happen in the future. One key consideration is the effect that acid deposition will have on the loss of nutrients from forest soils. There is little doubt that acid deposition can accelerate the loss of some nutrients from some soils. How much effect this may ultimately have on tree growth depends in part on a combination of other factors which affect nutrient capital.

The types of soils which might be most susceptible to nutrient loss have been identified, but the timing and magnitude of effects due to acid deposition induced nutrient depletion cannot be accurately predicted.

Another important consideration in predicting future effects is to define the effect of acid deposition on seedling establishment and growth in the current forests, since the forests of the future will be comprised of trees which reproduce and compete effectively. Acid rain can affect seedling establishment and growth, as shown in experimental research, but we do not have sufficient information to even speculate as to whether or not forest composition will change as a result of acid deposition.

Senator STAFFORD. Thank you very much, Dr. Johnson.

The next witness will be Dr. Dale W. Johnson, research staff member, Environmental Science Division, Oak Ridge National Laboratory, Oak Ridge, Tenn., to be followed by Dr. Orie Loucks.

STATEMENT OF DALE W. JOHNSON

Dr. DALE JOHNSON. Thank you, Mr. Chairman.

Since I have had rather late notice that I was going to testify here, yesterday morning, I would request your indulgence, so that I could finalize the draft before you and mail it out early next week. The draft before you is what I will essentially have to testify from.

Today I would like to address the effects of acid rain on forest nutrient status. I would like to acknowledge that much of the material that is in this text has come from documents I have helped prepare for the Office of Technology Assessment and the critical assessment documents for the Environmental Protection Agency.

In the interest of time, since I won't be able to get through all of this in 5 minutes, I would like to just jump to the summary and assessments section of that document that you have before you and be very brief. I refer you to the text for further details and also those other, upcoming documents for full details.

It is clear that acid rain in the form of sulfuric or nitric acid will increase the supplies of sulfur and nitrogen and decrease the supplies of cations by leaching in forest ecosystems. The only questions are: By how much and of what consequence are such increases or decreases to the overall nutrient status of the forest in question.

Since nitrogen limitations are so common and cation nutrient limitations are so rare in forests of the United States, it seems likely that nitric acid inputs will generally be beneficial. Exceptions will certainly occur on sites with adequate or excessive nitrogen supplies. Benefits of sulfuric acid deposition are probably minimal since sulfur deficiencies are rare and probably easily satisfied with moderate atmospheric sulfur inputs—much less than we are receiving in most of the United States today.

In terms of long-term effects—that is, many decades to centuries—acid rain can be expected to deplete total cation supplies in forests, and we must—and I stress this—we must assess this depletion rate within the context of natural leachings in soils. Acid leaching is not new to forest soils. We are talking about an increment to ongoing processes here. It must be assessed in that way.

It is not at all clear at this point whether depletion of total cations will cause reduced available cation supplies and acidification of soils. That is, cation leaching rates, though increased by acid rain, may well remain at insignificant levels relative to total soil supplies and forest growth requirements. Second, soil available cation supplies may be replaced by weathering from primary soil minerals at rates currently unknown and perhaps stimulated by acid rain inputs themselves.

In any event, the problem of assessing acid rain effects on forest nutrient status is entirely one of quantification of the amounts of inputs involved and the sulfur, nitrogen and cation nutrient status of the specific forest sites in question. By no means, can it be stated that forest ecosystems, in general, will respond to acid rain in any single way, and broad generalizations are hazardous.

I would like to use this quote, which I have used several times, by a 16th-century physician named Paracelsus which, while he was addressing the issue of human toxicity, I think applies to the issue of acid rain and forest nutrient status in many ways. And I quote:

> All substances are poisons; there is none which is not a poison; the right dosage differentiates a poison from a remedy.

Thank you.

Senator STAFFORD. Thank you very much, Dr. Johnson.

Dr. Orie Loucks is our last witness, science director, the Institute of Ecology, Indianapolis, Ind.

STATEMENT OF ORIE L. LOUCKS

Dr. LOUCKS. Thank you, Senator.

My name is Orie Loucks. I have been working in plant science for some 30 years and on the effects of acid rain for much of the past 5 years.

I recognize your committee has already taken considerable public testimony on amendments to the Clean Air Act. Accordingly, I will limit my observations to selected new results.

First let me address the question of how many lakes and how many miles of streams have been affected and where are they?

Over the past year we have undertaken an assessment to answer that question in four steps. First of all, we used mapping procedures from Oak Ridge National Laboratory which gave us a list of individual counties scattered over 27 Eastern States whose freshwater resources were potentially sensitive to acid deposition.

Second, we used the U.S. Geological Survey maps to sample each region so as to estimate the number of lakes greater than 15 acres in size, and total miles of first- and second-order streams within those counties.

Third, we took existing data from State and regional water quality surveys, emphasizing primarily the property called alkalinity, to estimate the percentage of the lakes and streams in these counties that could be considered sensitive to acid deposition, using a threshold of 200 microequivalents per liter of alkalinity.

The fourth step then answers the question of how many of these lakes can be judged to have been already altered by acid deposition in recent decades. Here we estimated the portion of the very low alkalinity lakes and streams that existed in the low alkalinity State prior to modern inputs of acidic deposition. We used as a threshold 40 microequivalents per liter of alkalinity. We dealt only with these very low alkalinity lakes because they occur infrequently in nature. Subtracting the natural background population from the modern distribution of low alkalinity lakes, shows that approximately 3,000 lakes in the Eastern 23 States are affected, and 23,000 miles of stream have alkalinity levels that can only be described as acid-altered.

There is still a good deal of uncertainty with these estimates, but reviewers looking at our report have charged us with seriously underestimating the results. We believe that further studies are likely to move these estimates upward.

A second question we addressed answers how much recovery might we expect in these resources from legislation such as that currently pending. Here we used a model to project future changes in lakes and streams, given a change in sulfate deposition. For one scenario of a 10-percent increase in sulfate deposition by the year 2000, as is possible in a relaxation of the Clean Air Act, we project 4 to 15 percent of the most sensitive lakes will worsen in condition over this period. A stricter scenario, with a 35-percent decrease in sulfate deposition by the year 2000, leads us to conclude that substantial recovery in 16 to 40 percent of the acid-altered resources can be expected.

Let us also address the question, then, of what ultimate loading target of sulfate appears to be warranted. Other studies we conducted dealt with four simple models for relating the magnitude of effects being observed to the level of acid deposition, thereby obtaining a preliminary dose-response relationship or tolerance. These four models are in remarkable agreement and they suggest a no-effect level of acidic deposition at about 12 kilograms per hectare of sulfate input, roughly a 100-percent increase over the historic levels of sulfate inputs. Another tolerance level which we call a practical minimal effect level—in other words, one that accepts the alteration of one or two lakes or streams per county—would be in the order of 16 to 20 kilograms per hectare.

Let me point out that current deposition in the highest regions is 48 kilograms per hectare, and we are, therefore, talking about a reduction, to a level between practical minimal effect or no-effect level, of about 75 percent from modern levels.

Let us now address the question of how much reduction in sulfate might be anticipated from reduction in SO_2 emissions. We have several studies that document the reduction in SO_2 emissions that have already taken place in the Northeastern regions of the United States. Results from the Hubbard Brook study, which are in my testimony, show that the deposition of the principal acidifying agent, sulfate, also peaked in the 1965–70 period and has been decreasing proportional to the reduction in SO_2 emissions. This gives us evidence that there is a close coupling between the proposed emissions abatement and the reduction in deposition that is assumed by our model.

Finally, let me close, Senator, with a personal observation. As a utility ratepayer in the State of Indiana, a State that will have to bear a considerable part of the costs of these abatements, I find the evidence persuasive that it is not technically possible to carry out the retirements and reschedule construction so as to achieve 10 million tons reduction of SO_2 within a decade. This level of emissions reduction is warranted, in my judgment, but the required planning of retirements and planning the retrofitting of large facilities will take several years. The design and construction of facilities will take additional years following that.

I think we all want to minimize costly mistakes. I suggest that you consider a 5-million-ton reduction now, which can be implemented without major construction of facilities, while at the same time directing a planning and analysis for the additional 5-million-ton abatement to take place in a decade following 1987.

This procedure would also allow the Congress to hold off a final decision on that second step until the results from the accelerated acid rain research plan are in hand and have been evaluated.

Thank you.

Senator **Stafford**. Thank you very much, Doctor.

We, for the committee, appreciate all of you helping us with the very difficult problem we face.

At this point, since Senator Byrd of West Virginia can't be with us this morning but was instrumental in asking us to hold these hearings, we will place his statement in the record. (See p. 25.)

Senator Mitchell, did you wish to comment on Senator Byrd's statement?

Senator **Mitchell**. Yes, I do. Thank you, Mr. Chairman.

I am sorry Senator Byrd was not able to make it here to testify today. In his statement and the material attached, he addressed the two principal issues. First, he urged no action on this matter now until such time, and I now quote his statement, "indisputable scientific agreement as to the causes and effects of acid precipitation" exist.

I would merely like to comment on that, that if the U.S. Congress had waited until there was indisputable scientific agreement as to causes and effects, it would never have enacted the Clean Air

Act, it would never have enacted the Clean Water Act, it would never have enacted the Safe Drinking Water Act, it would never have enacted the Toxic Substances Control Act, it would never have enacted the Resource Recovery Act, it would never have enacted the Noise Control Act, it would never have enacted the Clean Air Amendments of 1977, it would never have enacted the Clean Water Amendments of 1977, and the Senate would certainly never have enacted the Nuclear Waste Disposal legislation on which it acted just a few weeks ago.

The fact is that we cannot in ordinary human affairs ever hope to achieve indisputable scientific agreement, and that has never been a standard for action by this Congress in such matters. Were it to have been a standard, we would never have a single environmental law passed at any time in recent history or in the future. It is an impossible standard which obviously cannot be met with respect to this subject matter, nor should it be the standard.

Secondly, I would like to comment on Senator Byrd's materials regarding employment in coal mining in West Virginia. That is a very appropriate concern of Senator Byrd as a diligent representative of the people of West Virginia, as it has been of our own distinguished and beloved former chairman and now ranking minority member, Senator Randolph.

At the hearing on Tuesday, the subject was raised, and I at that time indicated a desire to submit material for the record on that point. I ask consent, Mr. Chairman, that there be submitted for the record a report by the Office of Technology Assessment entitled, and I quote, "The Effects of Acid Rain Control Measures on the Coal Market."

Senator STAFFORD. Without objection, that will be made a part of the record. (See p. 501.)

Senator MITCHELL. I would simply like to say that according to the Office of Technology Assessment, enactment of S. 1706 will result in an increase in employment in the coal-mining industry of West Virginia of from 6,900 to 9,900 jobs in 1990 over employment levels that would otherwise exist in that State at that time.

Now, the effect is regional in the State. In northern West Virginia, enactment of S. 1706 will produce a decrease in employment in the coal-mining industry in 1990 of from 1,200 to 1,700 jobs less than the employment level that would otherwise exist in that region in that industry at that time.

However, in southern West Virginia, enactment of S. 1706 will result in an increase in employment in the coal-mining industry of from 8,100 to 11,600 jobs in 1990 over employment levels that would otherwise exist in that region in that industry at that time.

The next effect is that failure to enact S. 1706 will cost the coal-mining industry of West Virginia somewhere between 8,100 and 11,600 jobs by 1990, a result we all devoutly do not hope for.

Thank you, Mr. Chairman.

Senator STAFFORD. Thank you very much, Senator Mitchell.

For myself, I intend to propose a few propositions and ask the members of the panel individually to agree or disagree with them separately.

As you know, on Tuesday the committee heard from a panel of atmospheric chemists and meteorologists on the subject of acid deposition. Since each of those panelists was of the same or a closely related field, we were able to obtain from them a consensus of the current state of scientific knowledge in that field. Noting that many of you are from different disciplines, I don't believe we could develop such a consensus statement today. To attempt to do that would force some of you to agree to statements relating to fields in which you or she have not carried out research that would give you special expertise.

However, I would like to piece together what each of you has had to say so that perhaps we can have a brief but accurate summary of what has been said today.

Before I begin that, though, I have to go back, Dr. Cowling, to the atmospheric ones in this country that appeared on two of your charts: one the conventional and the other the situation as you believe it exists more accurately. I wondered if it couldn't be possible that both in a sense were accurate, because my understanding is that weather patterns rotating either clockwise around highs or counterclockwise around lows do in fact generally move from east to west pretty much along the track lines that showed up on your first chart, while obviously the winds in rotation can pick up moisture from the Caribbean, dump it on Vermont, for example, or on a counterclockwise rotation or on a clockwise rotation.

Would there be anything to my observation?

Dr. COWLING. I think you are exactly right. The streaming lines I showed were for storm tracks, which more or less always move from west to east. It is not true that the net displacement in any given time or place is always from west to east.

Senator STAFFORD. Thank you.

First, Dr. Cowling, you have said that acid deposition is occurring over large portions of eastern North America; is that not correct?

Dr. COWLING. Yes, that is correct.

Senator STAFFORD. Dr. Noye Johnson, you have said that acid deposition mobilizes aluminum over vast areas and causes it to enter lakes and streams; is that correct?

Dr. NOYE JOHNSON. Correct.

Senator STAFFORD. Dr. Baker, you have said that dissolved aluminum is toxic in lakes and streams and that there has been observed fish mortality in Adirondack water; is that correct?

Dr. BAKER. Yes.

Senator STAFFORD. Dr. Dale Johnson, you agree, I believe, that acid deposition can result in accelerated leaching but believe that the ecological importance of this depends upon the reserves within that particular soil system. You also note that in some forest ecosystems low sulfur or nitrogen acid deposition can have a positive effect; is that correct?

Dr. DALE JOHNSON. That is correct.

Senator STAFFORD. Fifth, Dr. Arthur Johnson, you agree that acid deposition can have a positive or negative effect. However, in one particular area, namely the pine barrens of New Jersey, you noted that over a 20- to 30-year period acidity has increased and pitch pine growth has decreased. You also note that during the past 10 to 15 years there has been a sharp increase in red spruce mortality and that acid deposition is one of the few viable explanations; is that correct?

Dr. **Arthur Johnson**. That is correct.

Senator **Stafford**. Sixth, Dr. Loucks, you have combined data that indicate large portions of the northeastern United States are sensitive to the effects of acid deposition. Your data further indicates that not only are up to 80 percent of the lakes and streams in the region composed of the Adirondacks and New England sensitive to acid deposition, but roughly one of every four lakes or stream miles has already been altered by acid deposition; is that correct?

Dr. **Loucks**. Yes, sir. That is correct.

Senator **Stafford**. Dr. Lackey, you agree that acid deposition is occurring and believe that further research is needed; is that correct?

Dr. **Lackey**. Well, I am not sure exactly of both parts. I think basically further research is clearly needed to clarify some of these ambiguities.

Senator **Stafford**. You don't agree then that acid deposition is occurring?

Dr. **Lackey**. Yes, I agree with that part.

Senator **Stafford**. You agree with that. Thank you.

Dr. Evans, you have conducted a field study on soybeans, a very valuable cash crop in this country, and those studies indicate a 10-percent decrease in productivity at pH level 4.1; is that correct?

Dr. **Evans**. That is correct.

Senator **Stafford**. Dr. Cowling, your statement indicates that ambient rainfall of 4.1 pH occurs in Indiana, Ohio, West Virginia, and Kentucky, while ambient rainfall of slightly less acidity occurs in those four States plus Illinois, Tennessee, Virginia, Maryland, Pennsylvania, New Jersey, and New York; is that correct?

Dr. **Cowling**. Yes, that is correct. But if you link the statement that you asked if Lance Evans agrees with with the one you just made, I am not sure it would be a fair conclusion to draw that in fact we should expect from Lance's experience at Brookhaven that soybeans will necessarily be affected in the primary soybean growing regions of the United States.

Senator **Stafford**. Thank you.

Now I am going to make a brief statement as simply and individually as a U.S. Senator. Then I will yield to Senator Mitchell.

First, it appears to me, speaking individually, that it is clear that acid deposition is occurring. It is equally clear that a major source of acid deposition is from the industrialized Midwest, many States included.

Third, that acid deposition may or may not cause harm when it falls to Earth, but when it falls on soil which is sensitive, it is almost without doubt in fact a cause of harm. This harm includes reduced forest and crop productivity. And these reductions may be quite large.

Virtually the entire Northeast is sensitive to acid rain, and I gather from some of the diagrams we have seen today that the Appalachian region down over the Carolinas is also, and that over these regions acid rain is falling.

In short, acid rain is falling to ground where it can cause harm, and that ground includes, of course, northern New England. In addition to damaging life on or in the ground, acid rain can damage things on lakes and in streams. This harm is now occurring.

To put it plainly, I have heard from you as a panel that acid rain can kill or injure soybeans, trees, lakes, and streams, and there is a very good chance that it is doing exactly that in the parts of the country I referred to, including New England and my own State of Vermont. Therefore, it seems to this Senator, speaking again individually, that the stakes in the acid rain debate are enormous. Failing to take any action now risks an entire region of the country on a roll of the scientific dice, and that region includes my State. It may also jeopardize the economic well-being of farmers in the same region which produces the pollutants that lead to acid rain. Whether or not industries in the Midwest are willing to gamble the interests of Midwest farmers, this Senator is unwilling to see his State become table stakes in a debating match on this subject.

I see that Senator Chafee has returned. Do you have questions, Senator Chafee?

Senator **CHAFEE**. Thank you, Mr. Chairman. I had to go to an Intelligence Committee meeting just to appear for the confirmation of Mr. McMann as Deputy Director, so I missed some of the questions. If my questions are repetitive, I would appreciate it if you would tell me.

Senator **STAFFORD**. I can say, Senator, I didn't ask any questions really except to elicit agreement on eight or nine statements from individual members of the panel, and then I made a statement of my own that I didn't ask anybody to agree to.

Senator **CHAFEE**. My question is this: What has happened lately that has caused the acidity to suddenly become so destructive? After all, coal burning with higher sulfur coal and fewer restrictions has been going on in the Midwest for certainly a century, and at a high level certainly for 75 years, probably at a higher level than now. So, my question is what is all of a sudden happening to cause the acid rain and the low hydrogen-ion concentration levels to occur? Is it a culmination of the acid being there, coming down? Why don't I start with you, Dr. Noye Johnson?

Dr. **NOYE JOHNSON**. From the data we have at Hubbard Brook, we have—acid rain isn't only sulfuric acid. It is a mixture of sulfuric acid and nitric acid. It turns out that we have about two-thirds of the acidity attributable to sulfuric acid, coal if you like, and then the last fraction is nitric acid, which is presumably from the internal combustion engine.

At Hubbard Brook, when we have a very acid year or an acid rainfall, it is correlated highly with high nitric acid. So, the high acid periods we have are probably more directly related to nitric acid, internal combustion engines, than sulfuric acid. We seem to have had a steady input of sulfuric acid for at least 10 years.

Senator **CHAFEE**. Yes, but I mean, this has been going on for years. I presume obviously the amount of nitrogen from the engines has actually decreased over the past 4 or 5 years, or at best held constant. Yet suddenly this acid rain explodes on us as a major issue, I guess starting with, as you indicated, experiments in Sweden, the research in Sweden, and then it has come over here to

Hubbard Brook and other activities of all of you. So, Dr. Baker, why has it all of a sudden come to the fore?

Dr. **Baker**. This isn't my area of expertise, but I have the impression that part of the answer relates to long-range transport aspects, the building of the high smokestacks in Sudbury, for example. The lakes downwind about 65 kilometers weren't affected until they built the smokestack at Sudbury to disperse the local problem and, as a result, they transported it elsewhere. Suddenly those lakes 65 kilometers away then started to get the sulfate and the nitric acid input. It took 20 to 30 years, however, before they started to become acidified because each of these lakes has some buffering capacity to begin with. This buffering capacity must be used up before the lakes are going to start to acidify. So, you have the building of the smokestack at Sudbury to transport acid downwind and then the timelag to use up the natural buffering capacity of those lakes. Then you start to see acidification and then the loss of the fish populations and other effects.

Another reason for the explosion of the information is an explosion of research on acidic deposition. We have just started to go out and look for these problems. You can't have the data until you go out and look for it.

Senator **Chafee**. Yes; except I suspect the fishing in the Adirondacks has always been at a high level. People would have discovered dead lakes a long time, ago.

Dr. **Baker**. They did. In the sixties they studied the lakes in the Adirondacks. They'd had problems with fishkills. They couldn't figure out why. It took until the seventies to decide it was acid deposition. Also, for examples, the scattered reports of poor fish survival in hatcheries in Nova Scotia and Scandinavia. In Scandinavia they had problems in the thirties with poor fish survival in hatcheries. They knew it was acid conditions in the water because they limed the water and solved the problem. But it took until the sixties and seventies to decide it was acidity in the water due to acidity in the precipitation.

Senator **Chafee**. Dr. Loucks?

Dr. **Loucks**. I think, Senator, it might be useful to think of the analogy of a population exposed to mildly toxic gas over a long period of latency. You don't expect everyone in the population to express effects to that toxicity all at the same time. There are portions of the population that are more sensitive, and a portion that is probably tolerant. So, we have two factors operating. One is a differential in the numbers, watersheds, in the landscape, that will quickly respond, and the second has been cumulative—a larger and larger number over some decades. Thus, it was easy to miss the first evidence 20 to 30 years ago. With the cumulative impacts, over this period we now have relatively tolerant or somewhat tolerant watersheds also beginning to show the impact have to the duration of time. Now, in 1980, 1981, 1982, we are seeing the consequences of 30 to 50 years of exposure. It is very much easier to get a broad spectrum of evidence now than was possible even a decade ago.

Senator **Chafee**. About the suggestion that was made in testimony we had that the very efforts we are taking to reduce the sulfur—I am talking now just the sulfur in connection with the coal emissions—reduces the alkaline in it. By eliminating or pulling that down, we may be compounding our problem. Is there anything to that?

Dr. Cowling. I think this is somewhat a speculative question. The distance of transport of a gas through the air is very much larger than the distance of transport of particulate matter. So it is very likely that for nearby local sources, the removal of particulate matter would tend to increase the acid deposition locally. But the particulate matter will not go nearly as far as will the gaseous emissions, particularly if they are emitted at a very high elevation.

Senator Chafee. Dr. Baker talked about the Sudbury stack and it being built extremely tall, but I don't think that lately we have had—is there any change in the type of smokestack of a dramatic nature that has occurred in the past 20 years? Maybe that is one example. But overall smokestacks have been high for years, haven't they? Yes, Dr. Loucks.

Dr. Loucks. There has been a change in smokestack height over the past 30 years. A lot of the large plants, when we had severe pollution problems in Pittsburgh, had relatively low stacks, 100 to 150 feet. We have been through a period when we built stacks to 300 feet. Now in the Ohio Valley we build stacks to 900 feet. This has been systematically——

Senator Chafee. A stack of 900 feet?

Dr. Loucks. Yes.

Senator Chafee. Where is that?

Dr. Loucks. There are several. I believe that Clifty Creek is one, and there are others in Ohio. At this point there are about three stacks of 900 feet.

Senator Mitchell. If I may comment——

Senator Chafee. That is a formidable stack.

Senator Mitchell. If I may comment on that, Senator. The solution of every human problem contains within it the seed of a new problem. I think the tall stacks phenomenon is a perfect example of that.

When the Clean Air Act was passed in 1970, as a means of compliance—more accurately, in my judgment, as a means of noncompliance—tall stacks were built to produce the kind of dispersal that Dr. Baker testified about. That continued until the act was amended in 1977. So many of the very tall stacks in this country were built in the decade of the seventies as a response to the Clean Air Act. That I think has caused part of the problem.

Senator Chafee. Ship it east, in other words.

Senator Mitchell. That is right.

Senator Chafee. Let me ask you a final question. I know that there is a caveat as far as terrestrial damage goes, but does everybody agree that the aquatic ecosystem is damaged by the acid rain? Is there any dispute on that?

Silence indicates assent? Yes?

Senator Stafford. Do you want to poll the jury?

Senator Chafee. No. I will assume that they agree on that.

Now, I take it that there is some dispute on the panel as to the effect on terrestrial systems, forests. That is what I gathered from your comments. Am I correct? There is certainly not unanimity on that.

Dr. **ARTHUR JOHNSON**. I don't believe there is a dispute. I believe we all recognize we need more information to confirm what is or what is not happening.

Senator **CHAFEE**. Right. I would quantify it, in other words. Let me say we certainly appreciate what you have done. I personally believe this is the major environmental problem that we face in the balance of this century; and, indeed, if we don't solve it, it will be with us in the future. The effects seem so devastating, as has been pointed out by the testimony we have had today. Certainly this Senator is dedicated to getting on and doing something about it.

Thank you all very much.

Senator **STAFFORD**. Thank you very much, Senator Chafee.

Senator Mitchell?

Senator **MITCHELL**. Thank you, Mr. Chairman.

In your concluding remarks, Mr. Chairman, you described the seriousness of the problem, referring to it as high stakes. I would like to begin by trying to quantify that.

Dr. Loucks, as you will recall, on September 23, 1980, you testified before another Senate committee on the economic impact of acid rain. As you recall, I questioned you at that time. I would like now to read just a very brief portion of your testimony and then I am going to ask you, after I finish this, whether you still stand by that statement or whether it has changed in any way as a result of the information that has come to your attention in the intervening year and a half.

You testified, and this is the conclusion of a long statement, that:

> Combining the total effects from atmospheric deposition of oxidants on crops and acid rain on crops and fisheries, it appears that the total costs to the country are in the range of $65 billion to $75 billion, expressed as a cumulative total of potential benefits from now to the year 2000 for effective abatement.

I think I asked you, "This is in addition to the amount you described earlier attributable to oxidants?", to which you responded, "No, sir. The oxidant portion was $50 billion. The total for acid rain would be in the order of $15 billion to $25 billion." I then asked, "That is an aggregate total?" And you responded, "Yes."

As I understood your testimony then, it was that the total cost to the Nation over the last two decades of this century from the effect of atmospheric deposition of oxidants and acid rain would be $65 billion to $75 billion in your estimate, of which some $15 to $25 billion was the result of acid rain. Do you recall that statement?

Dr. **LOUCKS**. Yes, sir.

Senator **MITCHELL**. Would you tell me now, please, whether or not you still agree with the statement you made or whether you would care to amend or change it in any way?

Dr. **LOUCKS**. Let me emphasize, Senator, that those values are the present value accumulating future losses with a discount rate of 10 percent and expressing it as present capitalized value, which is what we would have to invest in the capital cost of abatement facilities if we were talking about that today. My answer to your question, Senator, is that yes, I believe those estimates are underestimating the current costs, the costs that one would project for that period today, given the additional evidence that we have in hand.

I am especially concerned with the increasing evidence that there are effects from acid rain on forest growth. This is not without uncertainty at this point, but given the increasing evidence to that effect, one would have to significantly increase that estimate of effects from acid rain.

Senator MITCHELL. Thank you. That is a very significant factor because there has been a great deal of discussion about the cost, especially to particular regions, of dealing with the problem. I wanted to make it clear that there is a very significant cost to not deal with the problem.

That leads me, Dr. Cowling, to your statement which you made right at the very conclusion of your remarks, in which you estimated that it would take about 5 years to complete what you described as the methodology and the planning for compliance and then another 5 years before any effect of compliance would be felt, an aggregate of 10 years from the time legislation was enacted.

It is, you would agree then, a fair statement to say that if we deferred action for 5 or 10 years, until we get more information, that the effects would then be delayed an additional 5 or 10 years. Is that a fair statement?

Dr. COWLING. Yes, it is. I would like to point out that during the 5 years of planning, we will of course continue to accumulate evidence of the sort you have heard from all of us today. So that some refinement in the planning can take place. If new evidence shows that crops are affected, we will add that to our data base, or if new evidence is brought forth there are benefits to forest growth, that can be figured into the equation as well.

Senator MITCHELL. I don't want to draw any unfair conclusion. I don't want to put any words in your mouth. But I take your statement to be generally supportive of the concept of taking some action now, at least beginning the process of action now, which will culminate in a beneficial effect some years hence.

Dr. COWLING. I believe that an earnest debate about how we would achieve significant reductions in sulfur and nitrogen oxide emissions would be a prudent course of action.

Senator MITCHELL. Unfortunately, Dr. Cowling, an earnest debate and action are not synonymous in any human arena, least of all in the U.S. Congress. But I appreciate your comments.

Dr. Dale Johnson, in your closing remarks you said, and I quote, in the next to the last paragraph of your statement, "By no means can it be stated that forest ecosystems in general will respond to acid rain in any single way."

I ask you, have you ever heard anybody say that?

Dr. DALE JOHNSON. Say what I just said?

Senator MITCHELL. Yes. In other words, you are negating a statement, and my question is, have you ever heard anybody make that allegation?

Dr. DALE JOHNSON. I have seen, I can't quote where, but I have seen statements and in fact heard in this hearing today statements that forests are being damaged or something to that effect. I think that sort of broad generalization is something that is really not valid considering the variability of forests. And there is potential response to acid rain.

Senator **Mitchell**. You have heard it said that forests are being damaged?

Dr. **Dale Johnson**. Yes.

Senator **Mitchell**. Every statement I have heard is very careful in its statement—potential, possible.

Dr. **Dale Johnson**. Yes. But in opening remarks and so forth we were worried about forests being damaged and so on. I have read this in the literature.

Senator **Mitchell**. Where?

Dr. **Dale Johnson**. Both popular literature and scientific literature.

Senator **Mitchell**. Can you identify a single specific source where you read that?

Dr. **Dale Johnson**. If I had with me the "First International Symposium on Acid Rain," I think I could. I can't be sure at this point.

Senator **Stafford**. If the Senator would yield, why don't we allow him to supply it for the record.

Senator **Mitchell**. I would like to ask you to do that, because I agree with you, and I think everybody else that has testified here does, and I have heard a lot of opponents of the bill say the proponents allege that forests are being damaged or that forests—I have never heard a proponent say that. I wish you would identify that source for me because I would like to write to whoever said that and tell them to stop saying that.

Dr. **Dale Johnson**. I have a file back at the lab I could pull out and send to you. Newsweek had an article, for example. I guess I won't say anything here other than that that I can recall specifically. But there have been those statements. A lot of them were some years ago, but much of this occurred before evidence began to come in or some thinking began to come in about the possible nitrogen-sulfur effects.

Senator **Mitchell**. I wish you would do so, because I am a proponent of this legislation and I have tried to be very careful not to make allegations that are unfounded regarding the effects of acid rain. I believe other proponents have as well. I think it is important that the debate be conducted within the bounds of accuracy and responsibility. I would want to encourage others who may be supporting this legislation, making claims that are not true, not to do so. As I said, I have never heard anybody who is for the bill say that. I have heard a lot of people who are against the bill claim proponents say that.

Dr. **Dale Johnson**. For the record, I guess the way I would state it is like this. It is often stated that we have evidence that forest growth is being negatively affected. You see this most often in introductory statements of effects. You see that far more often than you see statements to the effect that forests may be benefited. So I think there has been a bias in the way this thing has been viewed. There are two sides to the question.

Senator **Mitchell**. No doubt about that. That is one of the reasons I want to correct it. So if you would supply me with any specific references of the allegations you referred to. I want to undertake personally to try to set the person straight who made the allegation.

Dr. Dale Johnson. I will.[1]

Senator Mitchell. Dr. Loucks, I want to go back to one statement that is in your written testimony. We heard several hours of testimony on Tuesday from a distinguished panel of scientists, the subject of which primarily was cause and effect as it related to reductions in emission leading to reduction in deposition. You have made a statement that I simply want to repeat and emphasize. You said at page [illegible] of your statement, the next to the last sentence on that page, and I quote, "The fact is that sulfur dioxide emissions abatement is being matched by reduction in deposition of sulfuric acid, the principal acidifying agent." Have I read your statement correctly?

Dr. Loucks. Yes, sir.

Senator Mitchell. So it is your testimony, and when you say it is being matched, that at least creates the implication that it is based on past occurrences which have been measured.

I would like to ask you to expand on that because that is an important question in this entire debate.

Dr. Loucks. I think that we have heard this question posed in the following terms, Senator: That we have seen a 10- to 15-percent reduction in sulfur dioxide emissions in the eastern half of the country, but we have not seen a corresponding decrease in pH, which is true. I have introduced this portion of the testimony, Senator, to draw to the committee's attention the fact that we are seeing the reduction in the principal acidifying agent, sulfuric acid, in an amount that is proportional to the reduction in sulfur dioxide emissions. The pH of rainfall has been maintained at a relatively constant level because of the increases in nitrogen oxide and nitric acid over this period of time.

I think it is terribly important that the debate on the abatement of acid rain focus on the acidifying agent that is producing effects, which is principally sulfuric acid, although not solely. We have to be concerned about the nitric acid component, but nitrogen is, of course, a fertilizer. Although it helps to make the rain acid, it is not contributing in as large a way to the acidification of resources.

Senator Mitchell. But based upon that, would it be reasonable to anticipate that further reductions in sulfur dioxide emissions will result in further reductions of sulfuric acid deposition?

Dr. Loucks. Yes, sir.

Senator Mitchell. Thank you, Dr. Loucks.

I would like to ask Dr. Lackey a question. Doctor, you are with the Environmental Protection Agency?

Dr. Lackey. That is correct.

Senator Mitchell. You are aware, are you not, that the position of the Reagan administration and the agency with respect to acid rain is that we don't know enough about the problem to act now? Are you aware of that?

Dr. Lackey. That is my understanding of it.

Senator Mitchell. Are you here today representing the Environmental Protection Agency on this matter?

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[1] The information requested has been supplied to Senator Mitchell's office.

Dr. **Lackey**. No. Quite to the contrary. I am here as a scientist, an aquatic scientist, representing the national research program.

Senator **Mitchell**. The position of the administration and of the EPA has not in any way influenced your testimony or added to it here today?

Dr. **Lackey**. No, sir, not at all. In fact, I am in the Office of Research and Development. We are totally removed from the policy aspects of this question.

Senator **Mitchell**. You have testified that much needs to be better understood before informed regulatory decisions can be made. Actually, that is in your written statement. I don't think you said it quite that way. Can you tell me when in your judgment we will know enough to make an informed regulatory decision?

Dr. **Lackey**. I am not sure you ever really reach a point where you say you know enough to clearly make a decision. I would say the information based now on this particular question has lots of uncertainties. Frankly, I think in 5 years there will still be some uncertainties. There will certainly be less uncertainties, but we are not going to answer all of the questions. We will clarify some issues. When we will reach the point where policy or legislation should be made I think is beyond my scope. I basically am a scientist trying to assess the problem.

Senator **Mitchell**. Were you with the EPA in 1970?

Dr. **Lackey**. No, sir.

Senator **Mitchell**. Are you aware of the state of knowledge that existed regarding the subject matter of the Clean Air Act at that time and particularly how it compared with the present state of knowledge of the subject matter of this legislation?

Dr. **Lackey**. Only generally. I think the acid rain issue is not unique, I think as you are implying. I think the aquatic part of it is a complicated, technical issue. It is not dissimilar to other similar types of problems. There are still a lot of uncertainties in the area.

Senator **Mitchell**. There are still uncertainties with respect to the present subject matter of the Clean Air Act, are there not?

Dr. **Lackey**. Certainly.

Senator **Mitchell**. It is 12 years after we passed it.

Dr. **Lackey**. Yes.

Senator **Mitchell**. Do you think we should repeal the Clean Air Act?

Dr. **Lackey**. Well, I have to answer that, you know, as a private citizen. Technically, I think the issues are much more clearly defined. I think as a private citizen I would say that the Clean Air Act has done many good things, no question about it.

Senator **Mitchell**. What about the Clean Water Act?

Dr. **Lackey**. Well, being an aquatic biologist, I have a certain bias there. I think it has done a lot of good things, too.

Senator **Mitchell**. Safe Drinking Water Act?

Dr. **Lackey**. I am less familiar with the Safe Drinking Water Act. Again, my own bias is anything to do with water is probably good, so I expect it is.

Senator **Mitchell**. What about the Toxic Substances Control Act?

Dr. **Lackey**. I am very unfamiliar with that one.

Senator **Mitchell**. You are familiar with that one?

Dr. **Lackey.** No; unfamiliar with that one.

Senator **Mitchell.** What about the Nuclear Waste Disposal Act?

Dr. **Lackey.** I am extremely unfamiliar with that one.

Senator **Mitchell.** The point I want to make, of course, which I have made before, and I don't want to keep you here and belabor it, is there continue to be uncertainties in every area that is covered by environmental legislation. Indeed, not just environmental legislation. As I said on Tuesday, with no difficulty whatsoever I could assemble a panel of eight scientists to come here, half of whom would testify that there is no relationship between smoking and cancer. Do any of you believe that?

Senator **Stafford.** Senator, this would be a good time, if you would yield for a second, for me to place in the record, at the request of Senator Moynihan, a clarification of issues raised concerning the effects of acid precipitation on fish resources in the Adirondack region of New York State, which has been prepared by the Division of Fish and Wildlife of the New York State Department of Environmental Conservation.

Senator **Mitchell.** Thank you.

I merely would like the record to show that nobody responded when I said do any of you believe that. I will interpret that in the absence of an affirmative comment to mean that none of you believe that, that you all do believe that eight persons of different scientific backgrounds do believe that there is a relationship between smoking and cancer, even though we could assemble any number of scientists and any number of scientific papers which would have as their point and conclusion precisely the opposite.

What I am saying is that uncertainty exists in every aspect of human affairs. It exists to a very wide extent in environmental matters. And the argument that we don't know enough to act is the argument that has been used against every piece of environmental legislation that has ever been proposed in this Congress.

Now, the fact that it has been raised by opponents of prior legislation is not in and of itself a sufficient reason to dismiss it. The fact it was an invalid argument in previous cases does not in and of itself mean that it is invalid now. But I think we do have to address it.

I think those of us who support the legislation acknowledge the existence of uncertainties. The point is not, however, whether uncertainties exist. The point is whether there is a sufficient body of knowledge upon which to base a reasonable judgment now.

I think the evidence from this hearing as well as from the hearing on Tuesday is overwhelming—overwhelming—that we do indeed know enough about the causes and effects, particularly the enormous adverse effects, to justify action by the Congress now.

Mr. Chairman, I want to thank you for scheduling these hearings. I want to thank Senator Byrd for requesting them. I think they have been a source of great value and great education and have lent great weight to the urgency and need for the legislation which we support. I thank you all, Dr. Baker and you gentlemen, for your contribution in that effort.

Senator **Stafford.** Thank you very much, Senator Mitchell. I join in my appreciation of all members of the panel. You have been of great help to us in considering the problem of acid rain, as was the panel on Tuesday. Our gratitude and our assurance that the members who are not here because of debate on the floor or other committee meetings will examine the hearing record carefully in the course of our deliberations. So once again our thanks, and the meeting stands adjourned.

[Whereupon, at 12:25 p.m., the committee was recessed, to reconvene at the call of the Chair.]

[Statements supplied for the record follow:]

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United States Senate
COMMITTEE ON
GOVERNMENTAL AFFAIRS
WASHINGTON, D.C. 20510

June 9, 1982

The Honorable Robert T. Stafford
Chairman
Committee on Environment and Public Works
4204 Dirksen Senate Office Building
Washington, D. C. 20510

Dear Mr. Chairman:

I am writing to follow up on some of the questions raised during my appearance before your Committee on May 27.

First, let me express my appreciation again for your courtesy in allowing me to testify about my acid rain proposal, now embodied in S. 2594. Your deliberations on the Clean Air Act generally have been marked by a willingness to consider all proposals for improvement.

You asked me how much money would be generated by the proposed surcharge of 3 mils per kilowatt-hour sold within the acid deposition impact region. According to figures supplied by the Edison Electric Institute, in 1981 there was a total of 1,050,420 million kilowatt-hours of electricity sold within the 22-state primary region covered in my bill. Thus, for the first two years of enactment, the surcharge would raise approximately $3.15 billion per year, or $6.3 billion. In the third year, the nine-state secondary region, with 1981 sales of 417,601 million kilowatt-hours, could be included, and this would add $1.25 billion annually. Thus, in the first ten years the fund would accumulate a total of $31.5 billion from the 22-state primary region, and a total of $41.5 billion if all 31 states were included after the second year. This compares with an annual cost of compliance, as estimated by the Department of Energy, of $3.6 billion in 1980 dollars.

Senator Mitchell also inquired about the assumptions underlying my statement about the impact on utility rates within Missouri. Union Electric Company of St. Louis presented to the Committee staff on June 3 a lucid step-by-step explanation of its cost analysis, which shows a 20 percent rate impact from S. 1706. For a number of reasons set out at that June 3 inquiry, I believe their figures to be extremely conservative: if anything, they understate the impact. In addition, their estimates were corroborated by both formal and informal assessments of other utilities within Missouri. Along with the Union Electric paper, I enclose a paper prepared by Burns & McDonnell Engineering Company on the costs that would be incurred by Associated Electric Cooperative, Inc., which supplies power to rural electric cooperatives throughout Missouri.

This analysis, conducted independently of Unicom Electric's, shows a similar result--an increase in rates of 20 to 30 percent.

With regard to my statement that "recent scientific findings suggest that local sources of sulfur dioxide may play a far more important role in the creation of acid deposition than distant sources," I was trying to indicate a question of degree. I would not want to assert that long-range transport is not a factor in the acid rain phenomenon. But what are the distances involved? Common sense dictates that the impact of Missouri's emissions on Vermont is quite considerably less than that of Ohio's, simply because more of our sulfur will have fallen to earth before it reaches Vermont. That is why I have suggested holding nine states out of the acid deposition impact region--the nine states furthest from the vulnerable areas--until the extent of their contribution can be more clearly assessed.

In this regard, I would draw your attention to a paper written by Perry Samson and Mitchell Small of the University of Michigan and presented at the annual meeting of the American Chemical Society this spring: "The Use of Atmospheric Trajectory Models for Diagnosing the Sources of Acid Precipitation." I would be happy to provide a copy if that would be helpful.

There may be differences of opinion on this issue, of course, but you yourself expressed an unwillingness to risk your region "on a roll of the scientific dice." I am similarly unwilling to risk a massive economic shock to the Midwest in the form of increased utility rates. That is why I suggest sharing the cost, so that we can help your region without damaging mine.

I hope that this is sufficiently responsive to your questions. I would ask that this be made a part of the May 27 hearing record at the appropriate places.

Again, thank you for your willingness to let me testify and to consider the approach contained in S. 2594.

Sincerely,

John C. Danforth

Enclosures

ANALYSIS OF COST OF S.1706

UNION ELECTRIC COMPANY
ST. LOUIS, MISSOURI

Senate Bill 1706 would require an investment on the Union Electric system of $718 million and a minimum annual increase in electric revenue of $200 million (20%). This cost does not reflect the offset cost of any future emission increases.

The Union Electric system consists of four coal-fired power plants, three hydro plants, two oil-fired plants, and some combustion turbines that burn No. 2 oil. The oil-fired capacity emits an insignificant amount of SO_2. Therefore, only the four coal-fired power plants are included in this analysis.

This analysis assumes no monetary constraints, and that there would be no increase in cost of low sulfur fuel, rolling stock or scrubbers as a result of increased demand.

6/1/82
JDS

Union Electric Company
Summary of Costs to Comply with S.1706

Plant	Annual Increased Cost - $1,000,000
Labadie	94.6
Sioux	43.9
Rush Island	48
Meramec	15
	$201.5

1980 electric revenue = $996,893,000

Page 1 of 6.

A. Calculation of SO_2 Emission Reduction Necessary in Missouri to Comply with S.1706

1. Missouri SO_2 emissions in 1980 = 1,140,000 tons

2. 31-State region SO_2 emissions in 1980 = 15,959,000 tons

3. Missouri average SO_2 emission rate in 1980 = 4.92 lbs/mm Btu

4. 31-State region SO_2 emission rate in 1980 = 4.10 lbs/mm Btu

5. Missouri SO_2 emissions greater than 1.2 lbs/mm Btu

$$= \frac{(4.92 \text{ lbs/mm Btu} - 1.2 \text{ lbs/mm Btu})}{(4.92 \text{ lbs/mm Btu})} \times 1{,}140{,}000 \text{ tons}$$

$$= 862{,}000 \text{ tons } SO_2$$

6. 31-State SO_2 emissions greater than 1.2 lbs/mm Btu

$$= \frac{(4.10 \text{ lbs/mm Btu} - 1.2 \text{ lbs/mm Btu})}{(4.10 \text{ lbs/mm Btu})} \times 15{,}959{,}000 \text{ tons}$$

$$= 11{,}288{,}000 \text{ tons } SO_2$$

7. Missouri share of SO_2 emission reduction

$$= \frac{862{,}000 \text{ tons}}{11{,}288{,}000 \text{ tons}} = 7.64\%$$

8. Missouri SO_2 tonnage reduction required under S.1706

$$= (.0764)(10{,}000{,}000 \text{ tons})$$

$$= 764{,}000 \text{ tons}$$

NOTE: All data derived from E. H. Pechan report to EPA, September 1981.

B. Union Electric SO_2 emission reduction calculation to comply with S. 1706.

1. 1980 SO_2 emissions by plant

Labadie Plant = 237,000 tons
Sioux Plant = 97,200 tons
Rush Island Plant = 51,900 tons
Meramec Plant = 29,300 tons
Total 415,400 tons

2. Union Electric tonnage reduction assuming all sources in Missouri share an equal % reduction

$$\frac{764{,}000 \text{ tons - Missouri reduction}}{1{,}140{,}000 \text{ tons - emitted}} \times 415{,}400 \text{ tons}$$

$$= 278{,}390 \text{ tons}$$

3. Plant by plant SO_2 reduction allocation

	Actual 1980 tons	% reduction	S.1706 tonnage reduction
Labadie	237,000	71	168,270
Sioux	97,200	71	69,010
Rush Island	51,900	50	25,950
Meramec	29,300	50	14,650
	415,400		277,880

C. Examination of scrubber and low sulfur coal emission control options

1.

Plant	Plant Size Mw	Present Emission Limits, lbs-SO$_2$/mm Btu	S.1706 Emission Rates lbs-SO$_2$mm Btu
Labadie	2400	4.8	1.4
Sioux	1000	4.8	1.4
Rush Island	1200	2.3	1.2
Meramec	930	2.3	1.2

2. Additional coal costs per equivalent ton of fuel switched, and plant-by-plant costs

Plant	Capacity Factor, %	Incremental Coal Cost $/ton *	1980 Tons*	Additional Cost $1,000,000
Labadie	62	21	6.25	131
Sioux	49**	16.8	2.11	35(42.9)**
Rush Island	61	15.6	3.07	48
Meramec	42	9.6	1.46	14

* Adjusted to 10,000 Btu/#

** Capacity factor lower than desired. Additional compliance cost would rise to $42.9 million when adjusted to a 60% capacity factor.

3. Scrubber costs (See page 6 for assumptions in scrubber design).

Plant	Capital - $1,000,000	Annual Cost - $1,000,000
Labadie	498	94.6
Sioux	215	43.9
Rush Island	(248)*	(47.3)*
Meramec	(193)*	(36.6)*

* No equivalent detailed calculations available. Costs are scaled from the Labadie cost for comparison purposes.

Page 4 of 6.

D. Selected plan for estimating cost of compliance with S.1706.

1. A detailed engineering study for scrubber installation at Sioux and Labadie was completed in late 1976 (prepared by Gilbert Commonwealth Associates of Jackson, Michigan). Costs were based on start of construction 7/1/79, with start-up mid-1983.

2. Fixed charge rate has increased approximately 30% since these studies were completed. About 75% of total annual cost is the cost of ownership. Therefore, total annual cost as shown should be increased 20% to 25% to reflect current financing conditions.

3. Labadie: Scrubbers would be the lowest cost emission reduction alternative based on the data shown. This could quickly change if the cost of the present medium sulfur midwestern coal was to increase significantly on the system. It is very questionable whether compliance with particulate emission limitations could be achieved while burning a 1.4 lb-SO_2/mm Btu coal, even after completion of the ongoing project of upgrading precipitators. Therefore, the scrubber option is selected for this cost analysis.

   Sioux: The annual cost to own and operate scrubbers is about equal to the cost of low sulfur coal based on the data presented. After adjusting the cost of scrubber ownership to reflect a more representative fixed charge rate, scrubbers would appear to be more costly than low sulfur coal. However, experience has shown that burning high percentages (50% or greater) low sulfur coal can result in serious load limitations on the plant. In addition, precipitators at Sioux would not meet particulate emission limits while burning low sulfur coal. These factors support the scrubbers option at Sioux as the emission control choice for this analysis.

D. (cont'd.)

Rush Island:	The cost of the low sulfur coal option appears to be about equal to the scrubber option at Rush Island. This is the newest plant and has precipitators that would probably comply with particulate emission limits while burning low sulfur coal. Therefore, the low sulfur coal option was selected for purposes of this analysis.
Meramec:	Meramec is the oldest of the four plants. Its capacity factor is the lowest of the coal-burning plants and will probably decline somewhat in future years. Precipitator additions, completed on this plant in 1981 at a cost of $55/Kw, should achieve compliance with particulate emission limits while burning a lower percent sulfur coal. The low sulfur coal option is clearly the best choice for SO_2 emission reductions.

E. Scrubber design assumptions

1. Lime wet scrubbing

2. Reheating with hot gas bypass

3. Overall efficiency of scrubbers

Labadie	-	61.3%
Sioux	-	68.2%

4. SO_2 removal efficiency of gas scrubbed

Labadie	-	90%
Sioux	-	90%

Note: In order to achieve an overall removal efficiency of 71% at Sioux it would be necessary to remove 94% of the SO_2 from the gas scrubbed, or increase the size of the system to treat more of the gas volume. It would not be possible to achieve 71% removal at Labadie without treating a greater portion of the gas, thus requiring additional scrubber equipment.

5. No special treatment of scrubber sludge. Ten year pond life.

6. 40-hour work week. No overtime

7. Escalation 7% annually

8. Fixed charge rate -

Labadie	-	12.8%
Sioux	-	13.7%

9. Demand charge $590/Kw.

ESTIMATED ECONOMIC IMPACT OF PROPOSED ACID DEPOSITION REGULATIONS ON ASSOCIATED ELECTRIC COOPERATIVE, INC.

FOREWORD

By

Associated Electric Cooperative, Inc.

Associated Electric Cooperative, Inc., (AECI) is a not-for-profit electric generation and transmission cooperative headquartered in Springfield, Missouri. AECI owns and operates four coal-fired electric generating units with a net generating capacity of about 1700 MW. A fifth, 670-MW coal-fired unit is currently under construction and is scheduled to begin commercial operation in 1982. AECI provides power to about 415,000 consumers in rural Missouri.

AECI's four existing units would be affected by proposed acid deposition control legislation. AECI could be required to reduce SO_2 emissions to 1.2 lbs SO_2 per million Btu on about 70 percent of its total system capacity. As such, AECI is probably more affected by the proposed legislation than most other electric utilities in the midwest.

AECI is currently operating its units in compliance with Missouri regulations for existing sources. Reducing SO_2 emissions to 1.2 lbs SO_2 per million Btu would place an extremely heavy financial burden on AECI and the rural Missouri consumers who would have to pay the bill.

The following study shows that AECI could expect to spend about three-quarters of a billion dollars by 1988 to retrofit wet limestone scrubbers at its affected facilities. The study further shows that AECI could expect a first year increase in operating cost of about $175,000,000. This could increase the power rates to our consumers by 20 to 30 percent in 1988.

AECI is particularly concerned about this issue since there is no scientific evidence that these enormous expenditures by our ratepayers, as well as those in other midwestern states, will result in any reduction of acid deposition in the northeastern U.S. Legislation that would have such a tremendous economic impact on this country must be based on sound scientific data so there is a high probability that it will produce the desired results.

Acid deposition is a very complex problem. Far too little is known about the long-range transport of pollutants or the physiochemical processes that form acidic components of precipitation. Congress recognized these complexities in 1980 when it established the 10-year acid deposition study program.

AECI urges its elected representatives and its ratepaying members to oppose any acid deposition legislation at this time. We strongly support continued and accelerated research into the causes of acid deposition. Such research is currently being conducted by the Electric Power Research Institute. If these studies indicate a need for acid deposition precursor controls, rational and effective legislation can be formulated based on the data from these studies.

INTRODUCTION

This study has been prepared by Burns & McDonnell Engineering Company for the purpose of estimating the cost to Associated Electric Cooperative, Inc., of compliance with possible acid deposition control regulations. The cost estimates include both capital investments and first-year revenue requirements to install and operate wet limestone flue gas desulfurization (FGD) equipment at AECI's two coal-fired plants.

The Thomas Hill Plant is located in north-central Missouri about 6 miles northwest of Huntsville, Missouri. The plant consists of two coal-fired units with a third unit presently under construction and scheduled for commercial operation in 1982. The first unit, Unit 1, is rated at 180,000 kW and has been in service since 1966. Unit 2 is rated at 290,000 kW and has been in service since 1969. Unit 3 will be rated at 670,000 kW and will be equipped with a FGD system to limit sulfur dioxide emissions to 1.2 lbs/10^6 Btu. The fuel for the Thomas Hill Plant is high-sulfur, bituminous coal from mines owned and operated by AECI and located in Chariton, Randolph and Macon Counties, Missouri.

The New Madrid Plant is located in the Missouri bootheel, about 5 miles south of New Madrid, Missouri. The plant consists of two units each with a nameplate rating of 600,000 kW and placed in service in 1972 and 1977. These two units are fueled by high-sulfur, bituminous coal mined in southern Illinois.

RESULTS OF THE STUDY

A summary of the capital cost estimates for retrofitting wet limestone flue gas desulfurization (FGD) systems to both the Thomas Hill and New Madrid power plants is shown on the following table. The estimates are based on the following assumption and those stated in the following section:

1. Plant SO_2 emissions will be reduced to 1.2 lbs $SO_2/10^6$ Btu.

2. Wet limestone type flue gas desulfurization systems will be installed to achieve the above SO_2 reduction.

3. In-service date for the FGD systems will be 1988.

4. The project will be financed with tax-free pollution control bonds.

The construction cost estimates, developed in 1981 dollars, have been escalated to 1988 at a rate of 10 percent per year. The total construction cost estimates (1988$) also includes a 10 percent construction contingency.

The total financing requirements include, in addition to direct construction costs, indirect construction costs such as engineering, financing costs, interest during construction and other costs as itemized on the table.

CAPITAL COST ESTIMATES FOR WET LIMESTONE FLUE GAS DESULFURIZATION SYSTEMS IN SERVICE 1988 ($1000)

Item	Thomas Hill Power Plant			New Madrid Power Plant			
	Unit 1	Unit 2	Total	Unit 1	Unit 2	Total	Total
SO_2 Absorbers	$5.156	$7.917	$13.073	$13.769	$13.769	$27.538	$40.611
Site Preparation	666	1.000	1.666	1.500	1.500	3.000	4.666
Foundations and Substructures	3.494	5.034	8.528	9.923	9.223	19.146	27.674
Ductwork and Dampers	5.183	7.781	12.964	14.871	14.236	29.107	42.071
Chimney	4.010	—	4.010	11.437	—	11.437	15.447
Limestone Preparation Equipment	661	992	1.653	1.559	1.559	3.118	4.771
Miscellaneous Pumps	24	36	60	72	72	144	204
Sludge Thickener and Dewatering Equipment	993	1.491	2.484	2.982	2.982	5.964	8.448
Sludge Forced Oxidation Equipment	716	1.074	1.790	2.148	2.148	4.296	6.086
Materials Handling. Loading and Hauling Equipment	2.204	3.310	5.514	6.620	6.620	13.240	18.754
Gas Cleaning Structures	437	656	1.093	1.312	1.312	2.624	3.717
Process Piping	3.097	4.630	7.727	9.184	9.184	18.368	26.095
Instruments and Controls	3.013	3.013	6.026	3.013	3.013	6.026	12.052
Electrical Equipment and Power Wiring	2.806	3.494	6.300	7.537	6.987	14.524	20.824
Painting. Paving. Clean-up and Miscellaneous	718	1.078	1.796	2.155	2.155	4.310	6.106
Pneumatic Flyash Transfer System to Pug Mills	—	—	—	1.270	1.270	2.540	2.540
Escalation (1981-1988)	31.457	39.405	70.862	84.739	72.154	156.893	227.755
Contingency	6.465	8.089	14.554	17.409	14.816	32.225	46.779
Total Direct Construction Costs	$71.100	$89.000	$160.100	$191.500	$163.000	$354.500	$514.600
Engineering Fees & Expenses	$4.907	$6.230	$11.137	$13.405	$11.410	$24.815	$35.952
Other Studies	250	250	500	250	250	500	1.000
Overhead During Construction	1.700	1.600	3.300	1.700	1.600	3.300	6.600
Sales and Property Taxes	0	0	0	0	0	0	0
Initial Inventories	400	600	1.000	1.500	1.500	3.000	4.000
Spare Parts	600	750	1.350	1.600	1.400	3.000	4.350
Contingencies	2.500	3.000	5.500	7.000	6.000	13.000	18.500
Financing Costs	1.086	1.353	2.439	2.893	2.469	5.362	7.801
Interest During Construction	26.057	32.517	58.574	69.452	59.271	128.723	187.297
Total Indirect Costs	37.500	46.300	83.800	97.800	83.900	181.700	265.500
Total Financing Requirement	$108.600	$135.300	$243.900	$289.300	$246.900	$536.200	$780.100

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The annual cost (1988$) of ownership and operation have been computed on an accrual basis and are shown on the second table. These costs have been based on the following assumptions:

1. The escalation rate for fuel, limestone and operating labor costs will be 10 percent per year.

2. Interest on capital will be 13 percent per year.

3. Additional electrical generation capacity will be required by AECI to replace the capacity used by the FGD equipment.

4. Operating and maintenance labor and maintenance material costs will approximate those of power generation equipment.

It should be noted that these estimates are based on our judgement as to the types of systems, types of equipment and equipment arrangements which would be acceptable to AECI. Should these or any of the other above assumptions be invalid, the estimates could change significantly by the time the units are placed into service.

This study does not analyze the environmental or socioeconomic impact of the installation or operation of FGD systems at AECI's two plants. Likewise, alternatives to installing FGD systems such as the use of low-sulfur fuel, coal cleaning and recovery FGD processes which produce salable byproducts have not been evaluated.

ANNUAL COST OF OWNERSHIP & OPERATION OF WET LIMESTONE FLUE GAS DESULFURIZATION SYSTEMS
1988 ($1000)

Item	Thomas Hill Power Plant			New Madrid Power Plant			
	Unit 1	Unit 2	Total	Unit 1	Unit 2	Total	Total
Interest	$14.118	$17.589	$31.707	$37.609	$32.097	$69.706	$101.413
Depreciation	8.047	8.199	16.246	14.841	10.074	24.915	41.161
Insurance	272	338	610	723	617	1.340	1.950
Replacement Energy	1.200	1.650	2.850	2.250	2.250	4.500	7.350
Capacity Charge	1.064	1.596	2.660	2.527	2.527	5.054	7.714
Reagent	1.200	1.600	2.800	3.800	3.800	7.600	10.400
Operation & Maintenance Personnel	850	800	1.650	850	800	1.650	3.300
Maintenance Materials	425	400	825	425	400	825	1.650
Total	$27.176	$32.172	$59.348	$63.025	$52.565	$115.590	$174.938

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COST ESTIMATING METHODOLOGY

Because the majority of FGD systems installed in the U.S. utilize limestone in a wet scrubbing process and because the wet limestone systems are generally accepted as being the lowest cost, the limestone FGD system was assumed to be appropriate for this study. With this assumption in mind, the most accurate way to estimate the construction costs for the existing AECI units was to base the cost estimates on the anticipated costs to date for the FGD system at Thomas Hill Unit 3 which is scheduled to start-up in early 1982. Scale factors were applied to the base cost estimates where appropriate and additional costs for retrofit construction were included to account for limited space and requirements for remote location of a portion of the system.

Because construction costs were estimated in 1981 dollars, escalation at the rate of 10 percent per year was added to obtain estimated costs reflecting a 1988 in-service date for the FGD systems. A 10 percent contingency was added to the escalated cost estimate to arrive at the total estimated construction costs.

Estimated indirect capital costs were added to the total construction costs to arrive at the estimated total financing requirements. Indirect costs include:

1. Engineering costs, including administrative, design and related functions for specifications, bid analyses, procurement, field engineering, expediting, safety engineering and expenses.

2. Engineering costs and expenses for special studies including cost analysis and product evaluations.

3. Owner's overhead during construction including administrative, safety, engineering, legal and medical services.

4. Sales and property taxes were assumed to be zero for pollution control facilities.

5. Initial inventories of limestone reagent.

6. Spare parts for mechanical and electrical equipment.

7. Contingencies for indirect costs.

8. Financing costs as required to issue tax-free pollution control bonds.

9. Interest paid during construction less the interest received from the unused proceeds of the bond sales at the same rate as the bond interest rate.

In addition to investment, there will be substantial operating costs associated with the FGD equipment. These systems will consume between 2 and 3 percent of the generator output and 12 tons of limestone for each 100 tons of coal burned, and require an additional 25 operating and maintenance people at each plant.

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The annual cost of ownership and operation for each FGD system was, therefore, computed on an accrual basis to include the following:

1. Interest on capital at 13 percent per year.
2. Depreciation based on the remaining life of each unit.
3. Insurance.
4. Replacement energy.
5. Capacity.
6. Operation and maintenance personnel.
7. Maintenance materials.

It should be noted that the estimated costs for the above items apply only to the plants and type of FGD equipment assumed for this study.

LIMESTONE FLUE GAS DESULFURIZATION PROCESS DESCRIPTION

The limestone FGD process involves the recirculation of a limestone slurry to a scrubber. Limestone which has been ground in a wet milling system is added to the scrubber liquor in proportion to the sulfur dioxide removed by the scrubber. The scrubbing liquor or slurry is pumped to multiple scrubber vessels which are designed to produce intimate contact between the slurry and the sulfur dioxide in the gas. The sulfur dioxide is absorbed in the slurry and reacts with the limestone to form calcium sulfite and calcium sulfate. A portion of the slurry is bled to a thickener where the calcium sulfite-sulfate precipitate is separated and the liquor is returned to the scrubber. The calcium sulfite-sulfate is further dewatered in a centrifuge and finally mixed with dry fly ash for disposal in a landfill.

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Testimony on Acid Rain:
Its Causes and Consequences in the Environment

by
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Prepared for Public Hearings by the United States Senate
Committee on Environment and Public Works
Room 4200, Dirksen Senate Office Building
Washington, D.C. 20510
10:00 a.m. - Thursday, May 27, 1981

Statement by Dr. Ellis B. Cowling, Associate Dean for Research, School of Forest Resources and Assistant Director, North Carolina Agricultural Research Service, North Carolina State University, Raleigh, North Carolina 27650.

Prepared for Hearings on the causes and effects of acid deposition by the United States Senate Committee on Environment and Public Works.

Introduction:

For the past 21 years I have been a professor of Plant Pathology and Forest Resources at Yale and North Carolina State Universities. In 1970, I began a decade-long collaboration with Dr. Svante Odén, the Swedish soil scientist at Uppsala University, who first drew the world's attention to the acid rain problem in 1967-68. During the past 11 years, a significant part of my educational, research, and administrative efforts has been aimed at the development of a more adequate understanding of acid precipitation and its effects on plants, animals, surface waters, and materials in the United States.

Since 1976, I have led a group of about 150 scientists in 40 institutions and agencies in the United States and Canada in establishing the National Atmospheric Deposition Program (NADP). The NADP is a regional project of the State Agricultural Experiment Stations, various federal agencies, and private industries. Its major purposes are to: 1) encourage and coordinate research on the biological and other consequences of acid precipitation; and 2) to establish a long-term monitoring network to measure chemical changes in the chemistry of rain and snow in various parts of the United States.

In the fall of 1977, I joined with three other scientists from the NADP, in drafting a report to the President's Council on Environmental Quality entitled a: "National Program for Assessing the Problem of Atmospheric Deposition (Acid Rain)." This publication (Galloway et al., 1978)* provided the basis for the Presidential Initiative on Acid Rain which was announced in August 1979 (Carter, 1979).* During the summer of 1980, I also worked together with scientists in various federal agencies in developing the "National Acid Precipitation Assessment Plan" required by Title VII of the Energy Security Act of 1980 - P. L. 96-264 (IATFAP, 1981).*

In 1978, I encouraged the Board on Agriculture and Renewable Resources of the National Research Council to develop a detailed analysis of the life-supporting linkages between the atmosphere and the biosphere of the earth. This so called "Atmosphere-Biosphere Report" (NAS, 1981)* was issued recently by the National Academy of Sciences. I am very pleased to commend this report for careful study by the Congress.

Since August 1979 I have served as Program Director for a Cooperative Agreement between the Environmental Protection Agency, the National Atmospheric Deposition Program, and North Carolina State University. The purpose of this Agreement is to provide EPA with an improved understanding of the effects of acid deposition on aquatic and terrestrial ecosystems. This Agreement provides a major linkage between EPA and university research scientists who are concerned with the biological and water-quality effects of acid deposition in the United States.

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* See references listed in Item 4.

One of the most important outputs from this Agreement is a Critical Assessment Document summarizing the present status of knowledge about acid deposition and its environmental consequences. Forty-four scientists in 33 institutions and agencies throughout the United States and Canada have contributed to this Assessment which has been prepared under the leadership of my colleagues, Dr. Rick Linthurst of North Carolina State University and Dr. Paul Altshuller of the Environmental Protection Agency. This Document has been prepared at the request of the Clean Air Science Advisory Committee (CASAC) of EPA. The chapters of this Document are currently being revised in preparation for review by selected scientists, the public at large, and CASAC. It will be an important contribution of EPA to the National Acid Precipitation Assessment Program.

My testimony at these Hearings has been requested because of my knowledge and experience as a scientist. Thus, the ideas described here and in my verbal testimony before the Senate Committee are my own and may or may not be coincident with the policies and attitudes of the institutions and organizations with which I am affiliated.

Attachments:

Attached to and forming a part of this written testimony are several items which may prove helpful in considering the causes and consequences of acid rain.

Item 1) A map showing the distribution of acid precipitation across the United States and Canada. This map was developed by the NADP and CANSAP (Canadian) monitoring programs. Please note: (1) That precipitation with an average annual pH of 4.6 (10 times more acid than "normal") is occurring in every state and province of eastern North America; and (2) that precipitation with an average annual pH of 4.1-4.3 (40-50 times more acid than "normal") is occurring in large areas of the provinces of Ontario and Quebec in Canada and in the following states of the United States: Illinois, Michigan, Indiana, Ohio, Kentucky, West Virginia, Maryland, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine.

Item 2) A map showing the distribution of precipitation monitoring sites in the National Atmospheric Deposition Program in the various states of the United States. Please note that this program is now approaching the number (100) and distribution of collection sites (nationwide) that will be necessary to provide a continuing, accurate, and reliable record of change in the chemical climate of the United States.

Item 3) Two maps showing the distribution of sensitive surface waters in relation to major industrial sources of sulfur dioxide in North America. Please note that the sensitive surface waters of North America are well within the average daily travel distance of air from the major sources of sulfur and nitrogen oxides in this region.

Item 4) Selected references on the changing chemistry of atmospheric deposition and its effects on Aquatic and Terrestrial Ecosystems, Human Health, and Materials. Please note especially the references identified with an asterisk.

Item 5) A "Status Report on Acid Precipitation." This series of 41 documented statements provides a general introduction to principles the Congress needs to know about acid precipitation and its ecological consequences. This Status Report summarizes our present knowledge about many aspects of the acid precipitation problem. Please note especially:

--statements 1, 2, 3, 4, 7, 8, 9, and 12 under Atmospheric Chemistry, Transport, and Deposition;

--statements 14, 16, and 19 under General Effects on Ecosystems;

--statements 21, 22, 24, and 26 under Effects on Aquatic Ecosystems;

--statements 28-30 under Effects on Agricultural Crops and Forests; and

--statements 40 and 41 under Effects on Water Quality.

Item 6) A paper entitled "Acid Precipitation in Historical Perspective" which was published in the February issue of Environmental Science and Technology.

Item 7) A brief outline of research needs concerning acid precipitation and its ecological consequences. This outline has been taken from the National Acid Precipitation Assessment Plan prepared by the Federal Interagency Task Force on Acid Precipitation.

Item 8) A Table listing the responsibilities of various federal agencies in relation to acid precipitation.

Item 9) A copy of the Memorandum of Intent between the Government of Canada and the Government of the United States of America concerning Transboundary Air Pollution.

Item 10) A Conceptual Plan for Management of Acid Precipitation and its Effects on Aquatic Ecosystems in the Eastern United States and Canada. This draft document was prepared in December 1981 at the request of members of the House of Representatives Subcommittee on Natural Resources, Agricultural Research, and Environment.

General Comments and Conclusions:

The various maps and statements contained in the attachments to this testimony lead to the following general comments and conclusions:

1) Acid precipitation is occurring in very large areas across the North American continent (Item 1).

2) The areas receiving highly acid precipitation (average annual pH between 4.1 and 4.6, Item 1) include many regions in which surface waters and aquatic life are sensitive to and/or are presently being affected by acid precipitation (Item 3).

3) Much more is known at present about the nature, geographical location, and extent of detrminetal effects of acid precipitation on fish and other aquatic life, and drinking water quality than about possible effects on agricultural crops and forests. As I indicated in a recent National Research Council report (Cowling 1981): "The effects of acid precipitation and associated metal ion toxicity on aquatic ecosystems are sufficient to warrant preliminary formulation of management and ameliorative strategies" (Item 5, statements 21-24, 26, 40-41) [but] "the potential effects of acid precipitation on terrestrial organisms are not understood well enough to justify consideration of management strategies at this time" (Item 5, statements 15, 17, 28-31)

4) Gaseous emissions of sulfur and nitrogen oxides from combustion of fossil fuels are the principal sources of acidifying substances (Items 3 and 5, statements 2, 7). These

substances which are emitted mainly from power plants, smelters, industrial boilers, and transportation vehicles are deposited in urban-industrial, rural, and remote areas throughout eastern North America (Items 1 and 5, statements 1, 2, 7, 9).

5) The several states of the United States and provinces of Canada vary greatly in the total amounts of their sulfur and nitrogen oxide emissions and in their proximity to acid-sensitive geographical regions (Item 3 and pages 10-11 in Item 10).

6) The distance of transport of gaseous emissions leading to wet and dry deposition of acidifying substances is typically of the order of several hundred miles. Substantial vertical and horizontal mixing of air pollutants from many different and geographically separate sources occurs during transport over these distances (Items 1, 3, and 5, statements 1, 2, 8); thus, the direction of transport often is not the same as the direction of socalled prevailing winds. Also, atmospheric emissions of sulfur dioxide, nitrogen oxides, toxic metals, and other waste products in all states of the eastern United States and in all provinces of eastern Canada contribute to the deposition and accumulation of strong acids and other toxic substances in each of the major sensitive regions of eastern North America (Items 3 and 10).

7) Acid stress in aquatic ecosystems and mobilization of toxic metals into surface waters almost always are due to the cumulative effects of wet and dry deposition over a period of many weeks (prolonged summer drought), several months (winter snow accumulation), or even several years (gradual titration of clear-water lakes). For this reason long-term regional, seasonal and annual trends in the chemical climate of North America are much more important

biologically than the chemistry of specific meteorological events (Item 5, statements 14, 21, 22, 24, 26, and 40).

8) Approximately the same extent of acidification of an ecosystem is achieved whether the acidifying substances are deposited as gases, fine aerosol or coarse particles, or as dissolved substances in precipitation. This is true because the original emissions and their intermediate products are rapidly convereted to $SO_4^=$ or NO_3^- when they contact moist plant, animal, or soil surfaces (Item 5, statements 10, 11, 12).

9) Three alternative strategies of management for acid precipitation and its ecological consequences have been suggested:
   a) Decrease the amount of emissions leading to acid deposition;
   b) Use ameliorative treatments such as liming of watersheds or lakes and streams or controlled additions of alkaline materials to municipal reservoirs, or
   c) Develop acid-tolerant forms of aquatic life including both fish and fish-food organisms.

Assuming that alternative 1 is the alternative of choice as suggested by the recent Atmosphere-Biosphere Report of the National Academy of Sciences, emissions of sulfur and nitrogen oxides should be decreased by an amount sufficient to maintain the average annual acidity of precipitation above 4.6 or 4.7 (NAS, 1981). This estimate of a biologically acceptable acidity of precipitation is based on surveys of fish populations and water chemistry in acidified, partially acidified, and non-acidified lakes and streams in Europe and North America. A similar conclusion has been drawn by the Impact Assessment Working Group of the United States-Canada

Memorandum of Intent on Transboundary Air Pollution: "Wet sulfate loadings values of 11-20 kg/ha/yr have been suggested as being protective for the majority of surface waters." Keeping the pH of wet deposition in sensitive regions above 4.7 or the wet sulfate loading below 20 kilograms per hectare per year will require significant (30-50%) decreases in emissions of sulfur and nitrogen oxides throughout the eastern United States and southeastern Canada (Items 3 and 10).

10) It follows from the climatological and biological facts presented in statements 2-9 above, that a decreased-emission strategy to protect sensitive surface waters and aquatic life in any given region of eastern North America will require significant decreases in air emissions of sulfur and nitrogen oxides in most of the industrial regions of eastern North America. In this connection, it must be recognized that a given percentage decrease in emissions in one state or provide almost certainly will not produce an exactly equivalent percentage decrease in deposition in other states or provinces. Additional research on the chemical climatology of North America is needed to determine the extent to which changes in emissions in one state or province will alter the chemistry of deposition in other states and provinces. The next important scientific issue is to determine where and by how much will it be necessary to decrease emissions of acid deposition precursors in order to achieve the biologically acceptable extent of decrease in deposition that is recommended.

Development of An Acid-Rain Management Plan:

The following list contains a suggested sequence of steps for the evaluation of alternative strategies for the management of acid rain and its biological and water quality effects:

1) Determine the geographical location of sensitive natural resources and materials (lakes, streams, crop lands, forests, man-made structures, etc.) which are now being affected by acid precipitation or may be affected in the future.
2) Identify those resources which society wishes to protect.
3) Conduct a comparative analysis of various strategies by which the protection desired by society might be achieved. Alternative strategies would include the following:
    a) decrease the amount of emissions leading to acid deposition;
    b) use ameliorative treatments such as liming of lakes or application of protective coatings to materials; or
    c) develop acid-tolerant forms of life and structural materials.
4) Assuming that decreased emissions is the alternative of choice, as suggested in the recent Atmosphere-Biosphere Report of the National Academy of Sciences, determine the amount by which acid deposition will need to be decreased in order to avoid undesired effects on the resources selected for protection.
5) Determine where and by how much emissions of acid rain percursors will have to be decreased in order to achieve the

extent of decrease in deposition that will be required in the regions selected for protection.

6) Evaluate specific management strategies and tactics by which each selected source region could do its part to achieve the total emissions decrease that would be necessary. Possible methods would include the following:
   a) conserve fossil fuels;
   b) alter the mix of energy sources to include a higher proportion from non-polluting sources such as solar or possibly nuclear;
   c) use some combination of fuel cleaning, combustion modification, flue-gas treatment, etc.
   d) alter regulations to include existing as well as new sources, encourage "least-emissions-dispatching," permit the purchase and exchange of "pollution rights," etc.

Each of these suggested steps involves uncertainties that are analogous with those that surrounded the debates about the role of phosphorus in the eutrophication of Lake Ontario and Lake Erie in the early 1970's. The experts then could not agree. Some said a 40% decrease in loading would be needed. Others said 75%. Still others said nitrogen was to blame, not phosphorus. Environmentalists warned of "possible irreversible damage." Industry said more research was needed. Finally a political decision was reached--a plan should be developed. More debates were held. A theoretical model was used to predict that a 50% decrease in loading might be sufficient. Under conditions of substantial uncertainty a management plan was finally implemented. After some time the Lakes began to improve. The theoretical estimate was too low but with some further adjustments the plan worked and the Lakes are now on the road to recovery.

After a decision is made to proceed with preliminary evaluation of policies to protect sensitive regions from acid deposition, it probably will take at least five years to debate the scientific and management issues sufficiently to formulate an appropriate management plan. Also, at least another five years probably will be required to achieve an actual reduction in emissions. During the period of debate, new biological, atmospheric chemical, and meteorological insights will be developed which will help refine whatever management strategies may be recommended. Therefore, it seems prudent that we begin this debate and evaluation now, recognizing that research is continuing and that a decision to continue with present policies is one among many possible alternatives.

Summary:

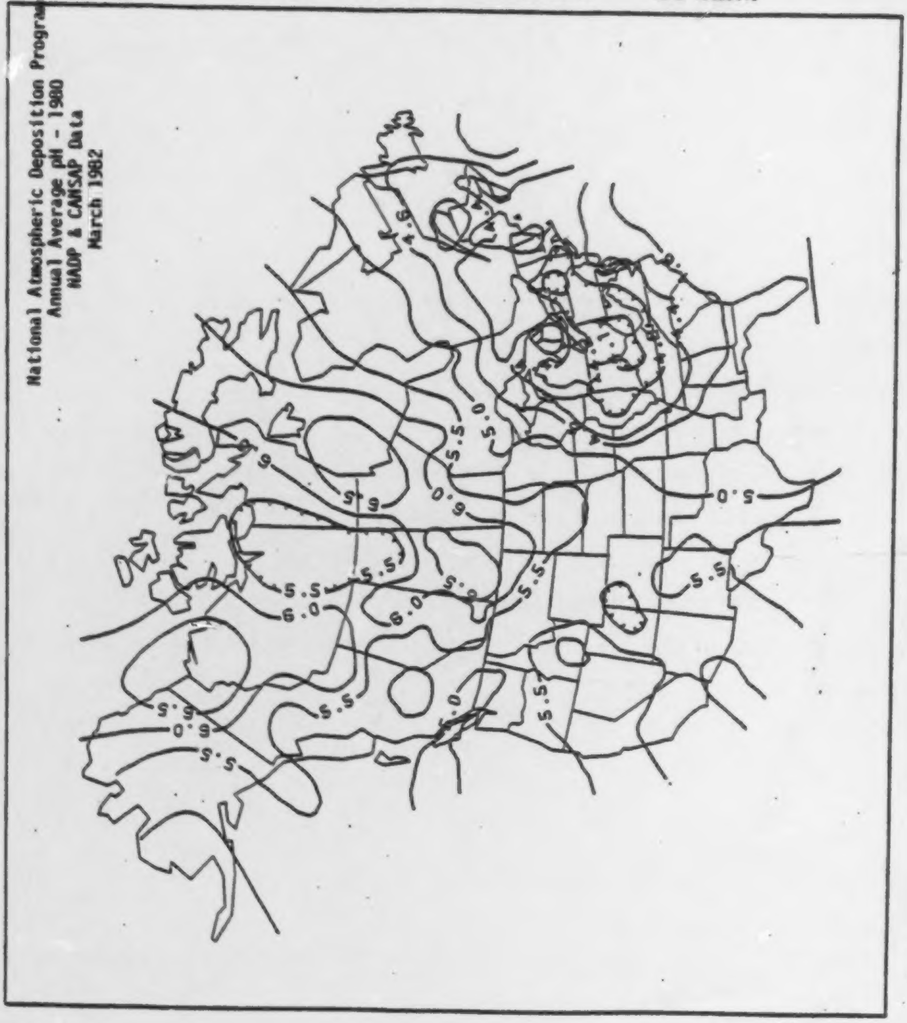
Much has been learned in recent years about acid precipitation and its effect on public welfare. But much also remains to be learned about many aspects of the problem and possible strategies for it solution. Today, public concern about acid rain is at an all-time high in many parts of the world. The recent Presidential and Congressional initiatives in acid rain research have culminated in the formation of a

Federal Interagency Task Force on Acid Precipitation and the recently implemented Federal Acid Precipitation Assessment Program (Items 6, 7, and 8). These initiatives call for a carefully coordinated program of policy-oriented research. Both these initiatives and the current air pollution treaty negotiations with Canada (Item 9) offer increasing hope that the United States will do its part, together with Canada, to develop in a timely way the additional knowledge that is needed.

Our present energy and environmental policies are resulting in change in the chemical climate of the earth. Important changes are taking place in the lakes, streams, fields, and forests on which both the abundance and the quality of our life depends. Wise management of these resources requires communication among biologists, hydrologists, atmospheric chemists, climatologists, regulatory strategists, and both industrial and political leaders in the United States and Canada. Let us continue that communication by focusing our collective knowledge on the development of more adequate plans for management of air quality and its effects on plants, animals, soils, surface waters, and materials. The current debate about possible revision of the Clean Air Act is one of the important occasions for such collective thinking.

Item 1

CONTOUR MAP OF PRECIPITATION WEIGHTED PH
PLOT NO. 2 DATE 82/03/04 TIME 15.38.15


National Atmospheric Deposition Program
Annual Average pH - 1980
NADP & CANSAP Data
March 1982
4.6
5.0
5.5
6.0
6.5

NATIONAL ATMOSPHERIC DEPOSITION PROGRAM
pH ISOPLETH MAP

pH Annual Average - 1980. Precipitation weighted. NADP and CANSAP data.

The pH Isopleth Map is drawn based on the precipitation weighted pH data for March 1979 to March 1980 from the NADP and Canadian CANSAP networks. The CANSAP data comprises approximately 50 sites, the NADP data, 38 sites. While the NADP network now has twice that number of operating sites, only sites for which twelve months of data was available for March 1979 to March 1980 are included. Certain areas of the country, particularly parts of the southeast and southwest, did not have sufficient sites which had operated for a one-year period to provide reliable data for drawing the contours. In these areas, the contour lines are dotted. This map is drawn by a computer program (SYMAP, Lab for Computer Graphics and Spatial Analysis, Harvard University), and there has been no "human" interpretation of the data in any region. The user of this information should be aware that techniques used for determining gradients from one site to the next do not necessarily represent natural variations in the parameter plotted. Therefore, care should be taken in interpreting this data. It presents only a very general picture on a regional basis, and should not be used to determine the pH at any specific location. There may be, for example, specific sites within a given isopleth which have values of the parameter outside of those which are included within the isopleth plot.

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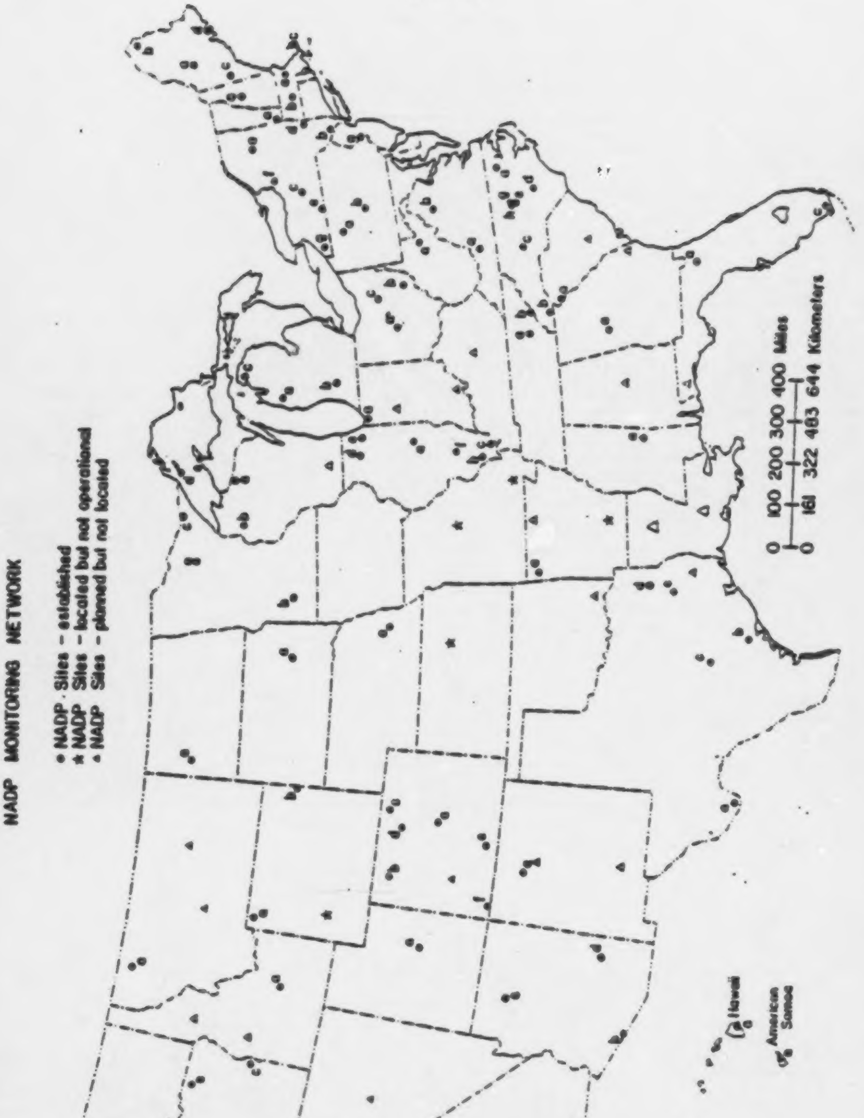
Item 2



NADP MONITORING NETWORK

● NADP Sites - established
★ NADP Sites - located but not operational
▲ NADP Sites - planned but not located
0 100 200 300 400 Miles
0 161 322 483 644 Kilometers
Alaska
0 250 Miles
Hawaii
American Samoa

Item 2 (continued)

NATIONAL ATMOSPHERIC DEPOSITION PROGRAM SITES

State	Code #	Site Name	County	Agency	Individual	Latitude	Longitude
Alaska (a)	020390	Denali (McKinley) N'l. Pk.		USDI-NPS	J. DalleMolle	63°48'	148°59'
Arizona (d)	030360	Oliver Knoll	Graham	USDI-BLM	D. C. Herkhof	33°04'	109°52'
Arizona (c)	030370	Grand Canyon National Park		USDI-NPS	L. May	36°04'	112°10'
Arizona (b)	030620	Organ Pipe Cactus N.M.	Pima	USDI-NPS	W. F. Wallace	31°57'	112°47'
Arkansas (a)	042700	Fayetteville	Washington	SAES-Univ. of Arkansas	G. H. Wagner	36°05'	94°10'
California (d)	053460	Bishop	Inyo	EPA/NOAA/WMO	J. Miller	37°22'	118°22'
California (f)	054200	Tanbark Flat (San Dimas)	Los Angeles	USDA-FS	P. R. Miller	34°12'	117°46'
California (b)	054540	Hopland	Mendocino	USDI-BLM	M. Ritchey	39°00'	123°05'
California (c)	057550	Sequoia-King's Canyon N. P.	Tulare	USDI-NPS	L. Bancroft	36°35'	118°46'
California (e)	058500	Channel Islands Nat'l Park	Ventura	USDI-NPS	Nick Whelan	34°01'	119°22'
California (a)	058840	Davis Site	Yolo	SAES-Univ. of California	R.H. Burgy	38°32'	121°46'
Colorado (e)	060060	Alamosa	Alamosa	EPA/NOAA/WMO	J. Miller	37°2[illegible]	105°52'
Colorado (f)	061530	Mesa Verde National Park	Montezuma	USDI-NPS	J. E. Smith	37°11'	108°29'
Colorado (b)	061560	Sand Spring	Moffat	USDI-BLM	D. Bray	40°30'	107°42'
Colorado (d)	061910	Rocky Mountain National Park	Larimer	USDI-NPS	D. R. Stevens	40°21'	105°33'
Colorado (a)	062120	Manitou	Teller	USDA-FS	D.G. Fox	39°06'	105°05'
Colorado (c)	062220	Pawnee	Weld	SAES-Colorado State Univ.	J.R. Gibson	40°47'	104°45'
Florida (a)	100360	Bradford Forest	Bradford	SAES-Univ. of Florida	H. Riekerk	29°58'	82°12'
Florida (c)	101190	Everglades National Park	Dade	USDI-NPS	P. Rosendahl	25°20'	80°40'
Georgia (a)	116140	Georgia Station	Pike	SAES-Univ. of Georgia	J.T. Walker	33°11'	84°24'
Hawaii (a)	120080	Mauna Loa	Hawaii	EPA/NOAA/WMO	J. Miller	19°32'	155°32'
Idaho (a)	130340	Craters of the Moon	Butte	USDI-BLM	K. Gebhardt	43°28'	113°34'
Illinois (a)	141160	Bondville	Champaign	SAES-Univ. of Illinois	G.J. Stensland	40°03'	88°22'
Illinois (d)	141800	NIARC	Dekalb	SAES-Univ. of Illinois	R. Bell	41°50'	88°51'
Illinois (e)	141980	Argonne	DuPage	Argonne National Laboratory	M. L Wesley	41°42'	87°59'
Illinois (b)	143580	SIU	Jackson	SAES-Southern Ill. Univ.	G.H. Aubertin	37°42'	89°16'
Illinois (f)	144740	Salem	Marion	EPA/NOAA/WMO	J. Miller	38°39'	88°58'
Illinois (c)	146340	Dixon Springs Ag. Ctr.	Pope	SAES-Univ. of Illinois	C.J. Kaiser	37°26'	88°40'
Indiana (a)	153420	Indiana Dunes Nat. Lakeshore	Porter	USDI-NPS	J. R. Whitehouse	41°38'	87°05'
Maine (d)	200010	Acadia National Park	Hancock	Maine Dep. Environ. Protection	L. Carver	44°23'	68°14'
Maine (b)	200045	Caribou	Aroostook	EPA/NOAA/WMO	J. Miller	46°52'	68°01'
Maine (c)	200277	Bridgton	Cumberland	Maine Dep. Environ. Protection	L. Carver	44°06'	70°43'
Maine (a)	200935	Greenville Station	Piscataquis	SAES-Univ. of Maine	S. A. Norton	45°25'	69°40'
Massachusetts (c)	220155	NACL	Barnstable	USDI-NPS	H. K. Foley	41°58'	70°01'
Massachusetts (b)	220815	Caldwell Creek	Hampshire	SAES-Univ. of Mass.	D. L. Mader	42°19'	72°23'
Massachusetts (a)	221325	East	Middlesex	SAES-Univ. of Mass.	W. A. Feder	42°22'	71°14'
Michigan (c)	230920	U of M Biological Station	Cheboygan	SAES-Michigan State Univ.	J. Boyle	45°34'	84°41'
Michigan (e)	232240	Houghton	Houghton	USDI-NPS & EPA	Robert Stottlemyer	47°14'	88°32'
Michigan (d)	232570	Isle Royale National Park	Keweenaw	USDI-NPS	Robert Stottlemyer	47°54'	89°09'
Michigan (b)	232660	Kellogg Biological Station	Kalamazoo	SAES-Michigan State Univ.	J. B. Hart, Jr.	42°29'	85°23'
Michigan (a)	235340	Wellston	Wexford	USDA-FS	D.B. Urie	44°13'	85°51'
Minnesota (a)	241660	Marcell Exp. Forest	Itasca	USDA-FS	E.S. Verry	47°30'	91°28'
Minnesota (c)	241840	Fernberg	Lake	EPA, ERL, & Forest Service	G. Glass	47°58'	91°29'
Minnesota (b)	242720	Lamberton	Redwood	SAES-Univ. of Minnesota	W. W. Nelson	44°15'	95°19'
Mississippi (a)	251460	Meridian	Lauderdale	EPA/NOAA/WMO	J. Miller	32°20'	88°45'
Montana (a)	270570	Glacier National Park	Flathead	USDI-NPS	D. Lang	48°30'	113°59'
Nebraska (a)	281520	Mead	Saunders	SAES-Univ. of Nebraska	S.B. Verma	41°09'	96°30'
New Hampshire (a)	300240	Hubbard Brook	Grafton	USDA-FS	J. Hornbeck	43°57'	71°42'
New Jersey (a)	312980	Washington Crossing	Mercer	EPA/NOAA/WMO	J. Miller	40°18'	74°51'
New Mexico (a)	320980	CUBA	Sandoval	USDI-BLM	C. Anderson	36°02'	106°58'

Item 2 (continued)

NATIONAL ATMOSPHERIC DEPOSITION PROGRAM SITES (Continued)

State	Code #	Site Name	County	Agency	Individual	Latitude	Longitude
New York (c)	330860	Aurora Research Farm	Cayuga	SAES-Cornell University	W.V. Knapp	42°44'	76°39'
New York (g)	331000	Chautauqua	Chautauqua	Niagara Mohawk Power	R. M. Wood	42°17'	79°22'
New York (d)	331220	Knobit	Columbia	NY State Electric & Gas	D. Matias	42°[illegible]7'	73°31'
New York (a)	332020	Huntington Wildlife	Essex	State U. of NY, Syracuse	D.J. Raynal	[illegible]°00'	74°13'
New York (b)	335140	Stillwell Lake-West Point	Orange	U. S. Military Acad.	Maj. J.E. Robertson	41°21'	74°02'
New York (f)	335240	Bennett Bridge	Oswego	Niagara Mohawk Power	R. M. Wood	43°30'	75°57'
New York (e)	336500	Jasper	Steuben	NY State Electric & Gas	D. Matias	42°07'	77°32'
No. Carolina (a)	340320	Lewiston	Bertie	SAES-N. Carolina St. & USGS	R.I. Bruck	36°08'	77°10'
No. Carolina (h)	341180	Research Triangle Institute	Durham	EPA	W. C. Eaton	35°54'	78°52'
No. Carolina (b)	342500	Coweeta	Macon	USDA-FS	J.E. Douglass	35°03'	83°27'
No. Carolina (g)	343310	Research Triangle Park	Durham	EPA/NOAA/WMO	J. Miller	35°52'	78°47'
No. Carolina (c)	343460	Piedmont Research Station	Rowan	SAES-N. Carolina St. & USGS	R. I. Bruck	35°40'	80°34'
No. Carolina (d)	343560	Clinton Crops Res. Stn.	Sampson	SAES-N. Carolina St. & USGS	R.I. Bruck	35°01'	78°17'
No. Carolina (e)	344160	Finley (Raleigh)	Wake	USDA-SEA & USGS	A. S. Heagle	35°44'	78°41'
No. Dakota (a)	350700	Theodore Roosevelt Nat'l Park	McKenzie	USDI-NPS	R. Powell	47°36'	103°15'
Ohio (a)	361760	Delaware	Delaware	USDA-FS	L.B. Bechinger	40°17'	83°04'
Ohio (b)	364900	Caldwell	Noble	SAES-OH Ag. Res. & Dev. Ctr.	T.C. Weidensaul	39°47'	81°31'
Ohio (c)	367160	Wooster	Wayne	SAES-OH Ag. Res. & Dev. Ctr.	T.C. Weidensaul	40°46'	81°56'
Oregon (a)	380200	Alsea Guard Ranger Station	Benton	EPA	C. F. Powers	44°22'	123°36'
Oregon (b)	380201	Schmidt Farm	Benton	EPA	C. F. Powers	44°38'	123°12'
Oregon (d)	380840	Lost Creek (Medford)	Jackson	USDI-BLM	G. Ferry	42°40'	122°37'
Oregon (f)	381020	H. J. Andrews Exper. Forest	Lane	USDA-FS	A. McKee	44°15'	122°10'
Oregon (c)	381120	Vines Hill (Vale)	Malheur	USDI-BLM	G. Ferry	43°54'	117°25'
Oregon (e)	381780	Pendleton	Umatilla	EPA/NOAA/WMO	J. Miller	45°41'	118°51'
Pennsylvania (a)	392940	Kane Exp. For.	Elk	USDA-FS	D.A. Marquis	41°33'	78°46'
Pennsylvania (b)	394200	Leading Ridge	Huntingdon	SAES-Penn. State Univ.	J.A. Lynch	40°39'	77°56'
S. Carolina (a)	421880	Clemson	Pickens	SAES-Clemson University	U.S. Jones	34°40'	82°50'
S. Dakota (a)	430060	Huron	Beadle	EPA/NOAA/WMO	J. Miller	44°23'	98°10'
Tennessee (a)	440060	Walker Branch Watershed	Anderson	Oak Ridge National Laboratory	S. E. Lindberg	35°58'	84°17'
Tennessee (b)	441190	Great Smoky Mtn. Nat. P.	Sevier	USDI-NPS	R. C. Mathews	35°40'	83°20'
Texas (a)	450425	Big Bend Nat. Park	Brewster	USDI-NPS	M. Warren	29°10'	103°12'
Texas (d)	452180	Longview	Gregg	Texas Air Control Board	S. Spaw	32°23'	94°43'
Texas (e)	453800	Forest Seed Center	Nacogdoches	Int. Paper Company	W. G. Humford	31°33'	94°52'
Texas (c)	455210	McKinney Falls State Park	Travis	Texas Air Control Board	S. Spaw	30°12'	97°43'
Texas (b)	455350	Victoria	Victoria	EPA/NOAA/WMO	J. Miller	28°51'	96°55'
Utah (a)	460280	Cedar Mountain	Emery	USDI-BLM	W. W. Wagner	39°10'	110°37'
Vermont (a)	470100	Bennington	Bennington	Vt. Agency Environ. Conserv.	R. L. Poirot	42°52'	73°09'
Virginia (a)	481300	Horton's Station	Giles	SAES-VPI & State Univ.	J. Shelly	37°11'	80°25'
Virginia (b)	482890	Shenandoah National Park		USDI-NPS	J. Shelly	38°31'	78°26'
Washington (a)	491410	Olympic Nat. Park (Hoh R.)	Jefferson	USDI-NPS	B. Moorhead	47°50'	123°55'
West Virginia (a)	501860	Parsons	Tucker	USDA-FS	S. H. Kunkle	39°06'	79°39'
Wisconsin (a)	513640	Trout Lake	Vilas	EPA	R. Becker	46°02'	89°38'
Wisconsin (b)	513700	Spooner	Washburn	EPA	R. Becker	45°50'	91°52'
Wyoming (b)	520820	Newcastle	Weston	USDI-BLM	T. E. Lukow	43°52'	104°11'
Wyoming (a)	520860	Yellowstone Nat. Park	Park	USDI-NPS	W. Hamilton	44°45'	110°35'
American Samoa (a)	530190	Samoa		EPA/NOAA/WMO	J. Miller	14°15'	170°34'

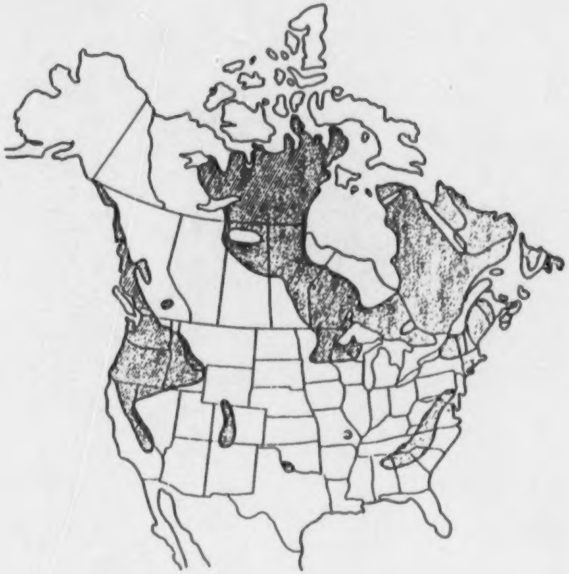
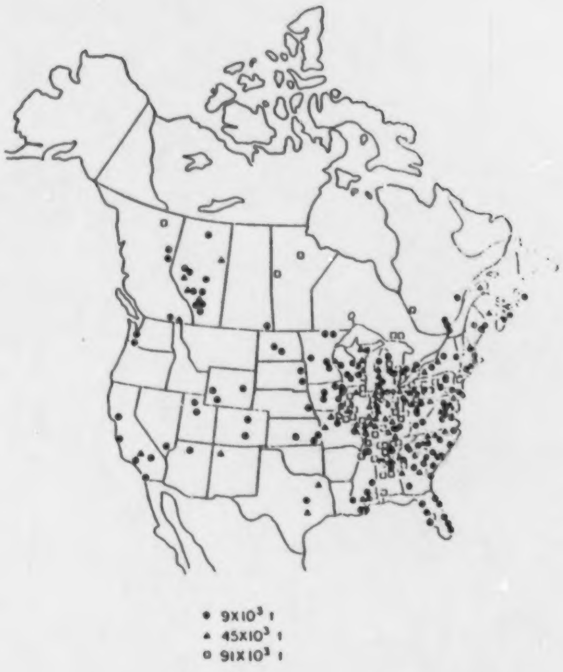


Figure 1-1a. Regions of North America (shaded) containing lakes sensitive to acidification (from Galloway and Cowling 1978).



● 9×10^3 t
▲ 45×10^3 t
○ 91×10^3 t

Figure 1-1b. Annual sulfur dioxide emissions in North America (from Graves 1980).

Item 4

SELECTED REFERENCES ON THE CHANGING CHEMISTRY OF ATMOSPHERIC DEPOSITION AND ITS EFFECTS ON TERRESTRIAL AND AQUATIC ECOSYSTEMS, HUMAN HEALTH, AND MATERIALS

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Item 5

A STATUS REPORT ON ACID PRECIPITATION AND ITS ECOLOGICAL CONSEQUENCES AS OF APRIL 1981

by Ellis B. Cowling[1]
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The following is a summary of the general status of knowledge about acid precipitation and its ecological consequences as of April 1981. In most cases these statements are a synthesis of observations and inferences derived from many independent investigations. It is beyond the scope and purpose of this account to provide rigorous and complete documentation; thus only a few key investigations are cited for each statement. Complete documentation can be obtained by consulting the original literature, access to which is provided by the following reviews and documents: Abrahamsen, 1980; Almer et al., 1974; Altshuller and McBean, 1979, 1980; Ambio, 1976; Bolin et al., 1972; Braekke, 1976; Cowling, 1980, 1981; Dochinger and Seliga, 1976; Drabløs and Tollan, 1980; Galloway et al., 1978; Gorham, 1976; Hendrey, 1978; Howells, 1979; Husar et al., 1978; Hutchinson and Havas, 1980; Likens, 1976; Likens et al., 1979; Malmer, 1973; NAS, 1975; Odén, 1968, 1976; Overrein et al., 1980; and Reuss, 1975.

Atmospheric Chemistry, Transport and Deposition

1. Acid precipitation (rain, snow, hail, dew, fog, frost) is occurring in large regions of the eastern United States and Canada, Europe and Japan. It has also been reported in certain urban and rural areas in the western United States and Canada and may occur in other regions of the world (Odén, 1968; McColl and Bush, 19[illegible]; Likens et al., 1979; Lewis and Grant, 1980).

2. This widespread occurrence of acid precipitation results in large part from man-made emissions of oxides of sulfur and nitrogen. These substances are transformed in the atmosphere to sulfuric and nitric acids, transported over great distances, and deposited on vegetation, soils, surface water and materials (Smith, 1872; Bolin et al., 1972; Likens, 1976).

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[1] Ellis Cowling has been engaged in acid precipitation research for the past 10 years. At present he serves as Chairman of the National Atmospheric Deposition Program (NADP), Program Director of the EPA-NADP-NCSU Acid Precipitation Program, Associate Dean for Research in the School of Forest Resources, and Assistant Director of the North Carolina Agricultural Research Service at North Carolina State University (NCSU). This status report is a product of interactions with scientists in each of these organizations and in the Swedish and Norwegian programs of research on acid precipitation. Critical review of this report by the following colleagues is acknowledged with appreciation: Svante Odén, Lars Overrein, Floyd Elder, Douglas Whelpdale, Gene Likens, James Galloway, George Hendrey, Eville Gorham, William McFee, Jay Jacobson, Norman Glass, and Orie Loucks.

3. Acid precipitation is only one mechanism by which air pollutants and other substances are transferred from the atmosphere onto plants, soils, surface waters, and structural materials. The other methods of deposition include 1) absorption and adsorption of gases, and 2) impaction and gravitational settling of fine aerosols and coarse particles. These other processes are called dry deposition (Junge and Werby, 1958; Galloway and Cowling, 1978).

4. The acidity (or alkalinity) of precipitation is measured in terms of pH units -- the negative logarithm of the concentration of hydrogen ions. Carbon dioxide combines with water in the air to form a dilute solution of carbonic acid at about pH 5.6. For this reason, acid precipitation is arbitrarily defined as precipitation with a pH value below 5.6. Because pH is a logarithmic scale, each unit change in pH represents a ten-fold change in acidity (Odén, 1968; Likens, 1976).

5. Evidence for the occurrence of long-term increases in the acidity of precipitation in North America includes the following: 1) changes in average annual pH value of precipitation in the years between 1955-56 and 1975-76, 2) changes in the alkalinity of surface waters; an especially valuable data set of this sort is available for the Hinckley Reservoir near Utica, New York between 1924 and 1980, 3) changes in the amounts and patterns of fuel use in the United States and Canada since the industrial revolution began about 1850; at present, about 95% of sulfur emissions in eastern North America are from man-made sources, and 4) changes in the sulfate and lead content of Greenland ice also since about 1850 (Beamish and Harvey, 1972; Cogbill and Likens, 1974; Cragin et al., 1975; Cronan and Schofield, 1979; Galloway and Whelpdale, 1979).

6. The ratio of sulfate to nitrate ions in precipitation varies from time to time and from place to place. In much of eastern North America the average equivalent ratio of sulfate to nitrate varies from about 3.3:1 in summer to about 0.7:1 in winter. The average annual ratio of sulfuric to nitric acids is currently about 2:1; but nitric acid is becoming progressively more important relative to sulfuric acid (Likens, 1976; Likens et al., 1979; Galloway and Likens, In press).

7. Tall stacks at power plants and smelters decrease nearby groundlevel concentrations of SO_2 and NO_x but simultaneously increase the geographical area of acid deposition. Removal of alkaline particulate matter from stack emissions also increases the acidic character of atmospheric pollutants and therefore the acidity of atmospheric deposition. (NAS, 1975; Braekke, 1976).

8. Analyses of air-mass movements and chemical transformations in the atmosphere indicate that acid precipitation in one state or region results in part from emissions into the atmosphere in other states or regions, often many hundreds of kilometers from the original source of the emissions (Odén, 1968; OECD, 1977; Galloway and Whelpdale, 1979; Altshuller and McBean, 1979, 1980; Husar and Patterson, 1980; Lyons, 1980).

9. Contemporary precipitation in industrial regions of the world is acidified mainly by man-made emissions of gases and particulate matter. Major anthropogenic sources include combustion of fossil fuels (especially coal and oil), certain industrial processes (especially smelting of ores), exhausts from internal combustion engines, and nitrogen fertilization of agricultural and forest land (Bolin et al., 1972; Kovda, 1975; Likens, 1976).

10. Changes in the acidity of precipitation are reflections of changes in the balance between the positively and negatively charged substances in precipitation. The more hydrogen ions (H+ ions) the greater the amount of acidity. Thus, to understand the acidity of precipitation, it is essential to measure all the major anions and cations in precipitation (especially hydrogen, sulfate, nitrate, and ammonium ions, but also including potassium, sodium, calcium, magnesium, chloride, bicarbonate, sulfite, and phosphate ions) (Likens, 1976).

11. All of the major anions and cations transferred into ecosystems when it is raining or snowing (wet deposition) also are contained in the gases and particulate matter that are transferred from the atmosphere into ecosystems when it is not raining or snowing (dry deposition). Thus, in a chemical mass balance sense, it is both impossible and unrealistic to distinguish the biological effects of "acid precipitation" (wet deposition) from the biological effects of dry deposition (Tamm, 1958; Kovda, 1975; Odén, 1976).

12. Some substances (such as ammonium sulfate) which themselves are not acidic can cause the acidification of soils when they are taken up by plants or modified by soil microorganisms. Thus, the concept of "acidifying precipitation" must be added to the concept of "acid precipitation" (Odén, 1976).

13. The potentially injurious substances in dry and wet deposition include not only acidic substances but also certain toxic gases and organic substances (notably pesticides) as well as various other inorganic substances (such as radioactive materials and asbestos fibers) or heavy metals such as manganese, zinc, copper, iron, molybdenum, boron, chlorine, fluorine, bromine, iodine, aluminum, arsenic, mercury, lead, nickel, cadmium, vanadium, etc. (Gorham and Gordon, 1960; Gorham, 1961; Tyler, 1972; Hutchinson and Whitby, 1974; Kovda, 1975; Galloway et al., 1980).

General Effects on Ecosystems

14. The underlined elements listed above are essential micronutrients needed by plants in small amounts. At higher concentrations, however, each of these same elements (and all the others) can be toxic to plants and animals. Furthermore, the acidity of precipitation can affect the solubility, mobility, and toxicity of certain of these elements. These substances can affect the following: 1) the foliage and roots of plants, 2) animals or microorganisms that may ingest or decompose these plants, 3) animals (including man) which may drink water containing these elements, and 4) animals (especially fish and other aquatic organisms) that live in chemical equilibrium with waters containing these substances (Ambio. 1976; Odén, 1976).

15. Significant quantities of plant nutrients, including nitrogen and sulfur, are being added to soil in dry deposition and in precipitation. These atmospheric inputs of beneficial nutrient elements are especially important in forests and rangelands where nutrients from other sources are scarce and where fertilization by man is not a normal management procedure (Hooke, 1687; Tamm, 1958; Wittwer and Bukovac, 1969; Cowling, 1980).

16. Short-term fertilization effects due to atmospheric deposition of ammonia and nitrate tend to offset long-term nutrient leaching and other detrimental effects of acid precipitation on forest ecosystems. Negative effects of atmospheric deposition on forest growth are most likely when nutrient deficiencies or imbalances are increased by acid deposition (Abrahamsen, 1980).

17. The net effect of atmospheric deposition can be beneficial or injurious to plants and animals depending on the chemical composition of the deposition (wet and dry), the duration and intensity of deposition episodes, the species and genetic characteristics of the organisms on which the substances are deposited, and the physiological condition, structure, and stage of maturity of the organisms (Grahn et al., 1975; Abrahamsen, 1980; Cowling, 1980; Lee et al., 1980).

18. Damage or injury to aquatic or terrestrial organisms is most likely when a particularly sensitive life form or life stage developing in poorly buffered waters or soils coincides (in time and/or space) with major episodic inputs of acid precipitation or other injurious substances (Borgstrøm and Hendrey, 1976; Leivestad et al., 1976; Likens et al., 1979; Hall et al., 1980).

19. Regions of greatest sensitivity to acid precipitation usually are recently glaciated, with large areas of exposed granitic (crystalline) and other noncalcarious bedrock and thin soils that are low in buffering and cation exchange capacity. The sensitive regions in North America include parts of New York, New England, large areas of Ontario, Quebec, and the maritime provinces of Canada, northern Minnesota, Wisconsin, and Michigan, parts of southern Appalachia and Florida, and large parts of Washington, Oregon, California, and Idaho. (Reuss, 1975; McFee, 1978; Galloway and Cowling, 1978; Abrahamsen, 1980).

20. Terrestrial and aquatic ecosystems are so intimately linked that it is both impossible and unrealistic to consider the effects of acid precipitation in aquatic ecosystems without considering its effects on terrestrial vegetation, soils, and the geology of the drainage basin (Braekke, 1976; Odèn, 1976).

Effects on Aquatic Ecosystems

21. Acids and other soluble substances contained in polluted snow are released as contaminated meltwater during warm periods in winter or in early spring. The resulting release of pollutants can cause major and rapid changes in the acidity and other chemical properties of stream and lake waters. Fish kills are a dramatic consequence of such episodic inputs into aquatic ecosystems (Odèn and Ahl, 1970; Leivestad et al., 1976).

22. Acid precipitation changes the acidity/alkalinity of lake and stream waters from conditions that are favorable for fish and other aquatic organisms to conditions that inhibit reproduction and/or recruitment of populations of fish and fish-food organisms (Hendrey and Wright, 1975; Henriksen, 1979; Leivestad et al., 1976; Henriksen, 1980).

23. In nutrient-poor lakes and streams between pH 6.0 and pH 5.0, reproduction of certain species of aquatic organisms is inhibited; below pH 5.0, populations of many freshwater fish will go to extinction (Beamish and Harvey, 1972; Dickson et al., 1973; Leivestad et al., 1976; Schofield, 1976).

24. Interference with normal reproductive processes in fish populations is induced not only by acidity itself but also by increased concentrations of certain cations - notably aluminum - in acidified lake and stream waters. Aluminum compounds vary greatly in toxicity to fish and other aquatic life. In general, ionic forms of aluminum are more toxic than aluminum complexed with organic matter (Hultberg and Grahn, 1976; Cronan and Schofield, 1979; Driscoll, 1980).

25. Reproduction of frogs and salamanders also is inhibited by atmospheric acidification of surface waters (Pough, 1976; Hagstrom, 1977).

26. As of 1980, hundreds of lakes in the Adirondack region of New York State, and many hundreds of lakes in various parts of southern Ontario and Quebec were showing acid stress in the form of diminished populations or extinction of fish populations. Lakes and streams in other regions of the United States and Canada also are vulnerable to stress by acid precipitation. These regions include northern Minnesota, Wisconsin, and Michigan; parts of southern Appalachia and Florida, and large parts of Washington, Oregon, California and Idaho and parts of the Canadian Maritime Provinces (Beamish and Harvey, 1972; Schofield, 1976; Galloway and Cowling, 1978; Altshuller and McBean, 1979; Hendrey et al., 1980).

Effects on Agricultural Crops and Forests

27. In certain industrial regions of the world, substantial damage to forests and agricultural crops is caused by the dry deposition of toxic gases. Sulfur dioxide, ozone, oxides of nitrogen, fluoride, and hydrogen chloride cause serious economic damage to crops and forests that must be considered together with the possible effects of acid deposition. Recent experiments have shown that a combination of acid precipitation and ozone caused greater reduction in yield of soybeans than ozone alone (Heck and Brandt, 1977; Shriner et al., 1980; J. Trioiano, personal communication).

28. Direct and indirect damage to crops and forests have been reported in laboratory, greenhouse, and field experiments in which synthetic rain equivalent (in chemical composition and rate of deposition) to natural rains has been applied. These biological effects include the following:

- Induction of necrotic lesions and other morphological changes in foliage (Shriner, 1978; Evans and Curry, 1979)
- Loss of nutrients due to leaching from foliar organs (Wood and Bormann, 1974)
- Predisposition of plants to infection by bacterial and fungal pathogens (Shriner, 1978)
- Accelerated erosion of waxes on leaf surfaces (Shriner, 1976)
- Inhibition of nodulation of legumes leading to decreased nitrogen fixation by symbiotic bacteria (Shriner and Johnston, 1980)
- Reduced rates of decomposition of leaf litter leading to decreased mineralization of organically-bound nutrients (Abrahamsen, 1980)
- Inhibited formation of terminal buds and increased mortality of pine seedlings (Matziris and Nakos, 1977)
- Both decreased and increased yield of certain agricultural crops (Evans and Lewin, 1980; Evans et al., 1980; Lee et al., 1980)
- Interference with normal reproductive processes (Evans and Conway, 1980).

29. Various specific biological effects of simulated acid rain have been demonstrated in controlled field and laboratory experiments (see item 28 above), but reliable evidence of economic damage to agricultural crops, forest and other vegetation, and to biological processes in soil by naturally occurring precipitation has been reported only rarely (Jonsson and Sundburg, 1972; Galloway et al., 1978; Cowling, 1980; Ulrich and Khanna, 1980; Tomlinson, 1981).

30. Recent experiments in Germany have demonstrated a significant correlation between amount of soluble aluminum in forest soils, death of feeder roots in spruce, fir, and beech forests, and widespread decline in the growth of these forests. Acid precipitation and dry deposition of acid-yielding substances have been postulated as a probable cause of these coincident effects (Ulrich et al., 1980; Schuck et al., 1979; Tomlinson, 1981).

31. Mushrooms, mosses, lichens, and other lesser vegetation in forests accumulate heavy metals, from the atmosphere, especially lead and cadmium. Wildlife feeding on these plants themselves accumulate the metals sometimes making both the plants and the wildlife hazardous for human consumption (Munshower, 1972; Huckabee and Blaylock, 1974; Tyler, 1980).

Effects on Soils

32. The consequences of acid inputs to soils vary greatly, depending upon the rates and recent history of atmospheric acid inputs, the character of the vegetation, natural rates of acid formation in the soil, and the physical-chemical properties of the soil (Wiklander, 1973; McFee, 1978).

33. Soil acidification increases leaching of exchangeable plant nutrients such as calcium, magnesium, potassium, iron, and manganese, and increases the rate of weathering of most minerals (Overrein, 1972; Reuss, 1975; Odén, 1976).

34. Acidification decreases the rate of many soil microbiological processes such as nit gen fixation and breakdown of organic matter. Various processes important in nutrient cycling, and critical in most ecosystems, are known to be inhibited by lowering soil pH. Included are the following: nitrogen fixation by Rhizobium bacteria on leguminous plants, by actinomycetes on some non-leguminous plants, and by certain blue-green algae and bacteria; mineralization of nitrogen from forest litter; nitrification of ammonium compounds; and overall decay rates of forest floor materials (Reuss, 1975; Braekke, 1976; Francis et al., 1980; Shriner and Johnston, 1980).

35. Atmospheric deposition of heavy metals also inhibits certain microbial processes in forest litter, especially decomposition of organic matter (Braekke, 1976; Tyler, 1976).

36. Acidification of soils reduces the availability of phosphorus to plants and increases the solubility of other elements, some of which may be toxic to plants. Aluminum is the most abundant toxic element in most forest and agricultural soils. Increasing soil acidity leads to greatly increased solubility and toxicity of aluminum to many crop and forest plants (Odén, 1976; Tomlinson, 1981).

37. Soils differ greatly in their susceptibility to acidification. Calcareous soils are unlikely to be damaged by acid inputs, but may be affected by metal deposition. Soils with low cation exchange capacity and degree of base saturation are very susceptible to increased acidification (Reuss, 1975; McFee, 1978).

38. Large quantities of hydrogen ions are added to soils as acid precipitation and as a result of cation uptake processes and both soil-amendment and fertilization practices. Acidification by these processes can be controlled by normal management practices in cultivated soils. But large areas of North America and Europe are not cultivated and have soils that are poorly buffered and therefore susceptible to further acidification. Many of these soils occur in forest and wilderness areas (Reuss, 1975; Odèn, 1976).

Effects on Water Quality

39. The chemical composition of lake, stream, and groundwaters is determined in part by the chemical composition of precipitation and dry deposition. The chemical composition of precipitation is modified by chemical and biological weathering and exchange processes as precipitation 1) washes over vegetation, 2) percolates through the soil, 3) interacts with the underlying bedrock of the drainage basin in which the precipitation occurs, and 4) runs off over the soil surface (Braekke, 1976; Odén, 1976).

40. Acid precipitation increases the solubility and mobility of many cations in soil. This increases the concentration of toxic metal cations including aluminum, manganese, and zinc in the soil solution. It also increases the leaching of nutrient cations including potassium, calcium, and magnesium, etc. These toxic and nutrients ions are transferred from soils into surface and groundwaters (Braekke, 1976; Oden, 1976).

41. Acidification of groundwaters has been found in western Sweden and attributed to long-term changes in the acidity of precipitation. As a result, hundreds of shallow dug wells and deeper drilled wells for home and farm buildings have shown acidities in the range between pH 4.0 and pH 6.0. A strong positive correlation has been found between the acidity of the well water and the content of metal ions including copper, zinc, lead, manganese, and aluminum. High concentrations of these metal ions in drinking water are hazardous to the health of people and livestock. In some cases, accelerated corrosion of copper piping and lead soldered joints has resulted in the necessity for early repair and/or replacement of copper piping systems (Hultberg and Wenblad, 1980).

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Acid precipitation in historical perspective

Awareness of the acid rain problem has developed in many countries over more than a century

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Some years ago the terms "acid precipitation" and "acid rain" were bits of esoteric jargon used almost exclusively by scientists in certain specialized fields of ecology and atmospheric chemistry. Recently, these terms have become worrisome household words in many countries around the world. While they have inspired sensational and sometimes exaggerated headlines about "death from the sky," they also have prompted a more deliberate and careful examination of the role of humans in the biogeochemistry and chemical climatology of the earth. How did this transition come about? Who was responsible? Why did it take so long for acid precipitation to be recognized as an important environmental problem? What factors of scientific awareness and public perception have influenced the course of research on acid precipitation?

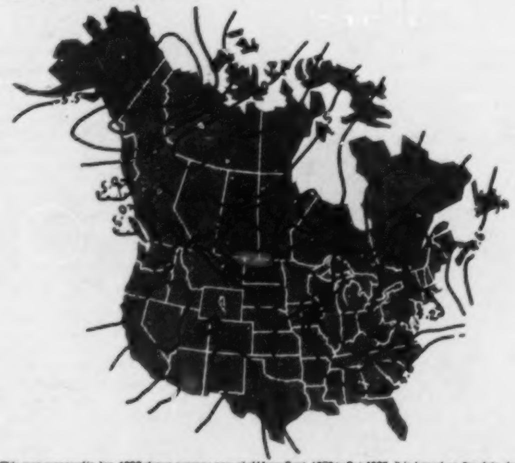
This brief article is an attempt to illuminate some of these questions. Our approach will be to review various steps in the transformation of the concepts of acid precipitation from the domain of scientific curiosity to the domain of public concern and debate.

Since the beginning of life on earth, plants have obtained an essential part of their nutrients from the atmosphere. From time to time, plants and animals have been injured by toxic substances dispersed in the atmosphere. When the industrial revolution started, people began to exert more and more influence on the biogeochemical circulation of the earth. We added progressively larger amounts of many kinds of substances to those that circulate naturally among the air, the water, the soil, and all living things. Some of these man-made materials were beneficial nutrients; some were inert; others were toxic or injurious depending upon their concentration or the nature of the organism receiving the deposition.

Because man now influences the chemical climate of the earth in so many important ways, it is essential that we understand the sources, transport, transformations, and chemistry of atmospheric deposition. We also must know the various effects that the deposited substances have on forests, fish, crops, soils, surface waters, and buildings and other structures (Figure 1).

Table 1 contains a historical resumé of the progress that has been made toward understanding these phenomena and their biological consequences. Contributions are presented in the chronological order of their occurrence, whether or not the work was recognized or accepted at the time. The names of major scientists, the country in which the research was conducted, and the principal contribution to science or public affairs are presented with appropriate references

FIGURE 1
About two-thirds of the total land area of North America receives acid precipitation[a]



[a] This map prepared in Jan. 1982 shows average annual pH from Sept. 1979 to Oct. 1980. It is based on the data developed by the National Atmospheric Deposition Program (NADP/NC-141) in the U.S. and the Canadian Network for Sampling of Precipitation (CANSAP) in Canada. These two networks prepared the first continent-scale map of atmospheric deposition for North America in 1980.

when that is possible.

Selecting particular accomplishments for inclusion in such a chronology is a hazardous undertaking because of the likelihood that some important contributions will not be given the credit or priority they deserve. I hope the table will serve a useful purpose, and look forward to receiving comments from anyone who may be interested in helping to describe the record more adequately.

Early awareness

Many features of the acid rain phenomenon were first discovered by an English chemist named Robert Angus Smith in the middle of the 19th century. In 1852, Smith published a detailed report on the chemistry of rain in and around the city of Manchester, England. In this remarkably early account, Smith called attention to the changes in precipitation chemistry as one moves from the middle of a polluted city to its surrounding countryside: "We may therefore find three kinds of air—that with carbonate of ammonia in the fields at a distance, that with sulphate of ammonia in the suburbs, and that with sulphuric acid, or acid sulphate, in town." Smith also pointed out that the sulfuric acid in city air caused the colors of textiles to fade and metals to corrode.

Twenty years later, in an extraordinary book entitled "Air and Rain: The Beginnings of a Chemical Climatology," Smith (1872) first used the term "acid rain" and enunciated many of the principal ideas that are part of our present understanding. On the basis of detailed studies in England, Scotland, and Germany, Smith demonstrated that precipitation chemistry is influenced by such factors as coal combustion, decomposition of organic matter, wind trajectories, proximity to the sea, and the amount and frequency of rain or snow. Smith proposed detailed procedures for the proper collection and chemical analysis of precipitation. He also noted damage by acid rain to plants and materials and commented on the atmospheric deposition of arsenic, copper, and other metals in industrial regions.

Unfortunately, however, Smith's pioneering and prophetic book apparently has been overlooked by essentially every subsequent investigator. Eville Gorham (1981) developed the first detailed analysis of Smith's early work for a report by the National Academy of Sciences.

Modern awareness

Contemporary concepts about acid precipitation and its environmental

TABLE 1

A historical resumé of progress toward understanding acid precipitation

Year(s)	Investigator and country	Principal contribution
1661–1662	Evelyn, Graunt, England	Noted the influence of industrial emissions on the health of plants and people, the transboundary exchange of pollutants between England and France; and suggested remedial measures including placement of industry outside of towns and use of taller chimneys to spread the "smoke" into "distant parts" (Evelyn, 1661; Graunt, 1662; see also Gorham, 1981)
1687	Hooke, England	On the basis of experiments by Brotherton, Hooke concluded that plants have "two-fold kind of roots, one that branches and spreads into the earth, and another that spreads and shoots into the air; both kinds of roots serve to receive and carry their proper nourishment to the body of the plant" (Hooke, 1687; see also Gorham, 1955; and Wittwer and Bukovac, 1969)
1727	Hales, England	Noted that dew and rain "contain salt, sulphur, etc. For the air is full of acid and sulphureous particles . . ." (Hales, 1727; see also Gorham, 1981)
1734	Linné, Sweden	Described a 500-year-old smelter at Falun, Sweden: ". . . we felt a strong smell of sulphur, . . . rising to the west of the city . . . a poisonous, pungent sulphur smoke, poisoning the air wide around . . . corrode(ing) the earth so that no herbs can grow around it" (Linné, 1734)
1852	Smith, England	Analyzed the chemistry of rain near Manchester, England and noted concentric zones with "three kinds of air—that with carbonate of ammonia in the fields at a distance, that with sulphate of ammonia in the suburbs, and that with sulphuric acid, or acid sulphate in the town." Smith also noted that sulfuric acid in town air caused fading in the color of textiles and corrosion of metals (Smith, 1852; see also Gorham, 1981, Austria)
1854–1856	Austria and Germany	Established "General Citizens Laws" prohibiting disposal of wastes by individuals on a neighbor's property. In the interest of encouraging industrialization, however, these same laws specifically excluded industries from legal liability when waste disposal caused pollution of water and air
1855–1856	Way, England	Completed a very detailed series of analyses of nutrient substances in precipitation at the Rothamsted Experiment Station and showed the value of these substances in crop production (Way, 1855)
1872	Smith, England	In a remarkable publication entitled "Air and Rain: The Beginnings of a Chemical Climatology," Smith first used the term "acid rain" and enunciated many of the ideas that we now consider part of the acid precipitation problem. These ideas included regional variation in precipitation chemistry as it is influenced by such factors as combustion of coal, decomposition of organic matter, wind direction, proximity to the sea, amount of rain, etc. After extensive field experiments, Smith proposed detailed procedures for the proper collection and chemical analysis of precipitation. He also noted acid rain damage to plants and materials and atmospheric deposition of arsenic, copper, and other metals in industrial regions (Smith, 1872; see Gorham, 1981)
1881	Brögger, Norway	Observed "smudsig snefald" (dirty snowfall) in Norway and attributed it to either a large town or an industrial district in Great Britain (Brögger, 1881)
1909	Sørensen, Denmark	Developed the pH scale to describe the acidity of aqueous solutions (Sørensen, 1909)
1911	Crowther and Ruston, England	Demonstrated gradients in acidity of precipitation decreasing from the center of Leeds, England; associated the acidity with combustion of coal; and showed that both natural rain and dilute sulfuric acid inhibited plant growth and seed germination, as well as ammonification, nitrification, and nitrogen fixation in soil

Year(s)	Investigator and country	Principal contribution
		(Crowther and Ruston, 1911; see also Cohen and Ruston, 1912; and Gorham, 1981)
1919	Rusnov, Austria	Demonstrated that deposition of substances from the atmosphere accelerated the acidification of both poorly-buffered and well-buffered forest soils (Rusnov, 1919)
1921	Dahl, Norway	Recognized the relationship between acidity of surface water and trout production (Dahl, 1921, 1927)
1922	Atkins, England	Measured the alkalinity of surface waters and noted a relationship between alkalinity and biological productivity (Atkins, 1922)
1923	MacIntyre and Young, U.S.	Made the first detailed study of precipitation chemistry in the U.S. (MacIntyre and Young, 1923)
1925	Shutt and Hedley, Canada	Made very early measurements of the nitrogen compounds present in rain and snow and commented on the value of these compounds for crop growth (Shutt and Hedley, 1925)
1926	Sunde, Norway	Demonstrated the value of adding limestone to water in a fish hatchery (Sunde, 1926)
1939	Erichsen-Jones, Sweden	Demonstrated the relationship between acidity and the toxicity of aluminum to fish (Erichsen-Jones, 1939)
1939	Katz et al., Canada	Reported acidification and decreases in base saturation of soils caused by sulfur dioxide emissions from the lead–zinc smelter near Trail, British Columbia (Katz et al., 1939)
1939	Bottini, Italy	Detected hydrochloric acid in precipitation near the volcano on Mount Vesuvius, thus demonstrating that there are natural sources of strong acids in precipitation (Bottini, 1939)
1942	Conway, Ireland	Completed the first modern review of precipitation chemistry (Conway, 1942)
1948	Egnér, Sweden	Initiated the first large-scale precipitation chemistry network in Europe (Egnér et al., 1955; Rossby and Egnér, 1955)
1950–1955	Eriksson, Sweden	Enunciated a general theory of biogeochemical circulation of matter through the atmosphere (Eriksson, 1952, 1954, 1959, 1960)
		Expanded the regional network established by Egnér into the continent-wide European Air Chemistry Network, which has provided a continuing record of precipitation chemistry for three decades (Emanuelsson et al., 1954)
1953	Viro, Finland	Developed a regional chemical budget by comparing analytical data for precipitation and river waters in Finland (Viro, 1953)
1953–1958	Tamm, Sweden	Demonstrated the great dependence of mosses on atmospheric sources of nutrients, especially nitrogen (Tamm, 1953) and expanded this concept to include most forest plants (Tamm, 1958)
1953–1955	Various investigators in several countries	Simultaneously investigated precipitation chemistry data for evidence of atmospheric acidity (Barrett and Brodin, 1955, Sweden; Parker, 1955, and Gorham, 1955, England; Houghton, 1955, U.S.)
1954–1961	Gorham, England	Demonstrated that acidity in precipitation markedly influenced geological weathering processes and the chemistry of lake waters, bog waters, and soils (Gorham, 1955, 1958b, 1958c, 1961)
		Demonstrated that hydrochloric acid from combustion of coal rich in chlorine predominated in urban precipitation whereas sulfuric acid predominated in rural precipitation (Gorham, 1958a, 1958d)
		Established that acidity in precipitation affects the alkalinity and buffering capacity of lake and bog waters (Gorham, 1957, 1958a)
		Established that the incidence of bronchitis in humans can be correlated with the acidity of precipitation (Gorham, 1958)

effects originated in three seemingly unrelated fields of science: limnology (the study of lakes), agriculture, and atmospheric chemistry.

Progress in limnology. The relationship between rain or snow and the water in streams and lakes was obvious even to prehistoric man. But the connection between changes in the chemistry of rain and snow and alterations in the chemistry of lake waters remained obscure until the middle of the 20th century.

In a long series of papers beginning in 1955, Gorham (1955, 1957, 1958a–d, 1961, 1965), now professor of ecology at the University of Minnesota, built the major foundations for our present understanding of the causes of acid precipitation and its impact on aquatic ecosystems. On the basis of research both in England and in Canada, Gorham and his colleagues demonstrated the following principles:

- Much of the acidity in precipitation near industrial regions can be attributed to atmospheric emissions produced by the combustion of fossil fuels;
- Progressive losses of alkalinity in surface waters and increases in the acidity of bog waters can be traced to the atmospheric deposition of acidic substances by precipitation;
- The free acidity in soils receiving acid precipitation is due primarily to sulfuric acid;
- The incidence of bronchitis in humans can be correlated with the acidity of precipitation;
- Exposure to sulfur dioxide and the resultant acid rain contribute to the deterioration of vegetation, soils, and lake water quality around metal smelters.

Thus, by the mid 1950s and early 1960s, Gorham was the second scientist to establish a major part of our present understanding of the sources and environmental consequences of acid precipitation. But his pioneering research, like that of Smith a century before, was met by thundering silence from both the scientific community and the public at large. One plausible explanation is that Gorham's work, being highly interdisciplinary, was published in a diverse array of scientific journals. In any event, because Gorham's work was not recognized, there resulted a further lag in both the scientific and public awareness of acid precipitation.

Progress in the agricultural sciences. The importance of the atmosphere as a source of nutrients for the growth and development of plants was first recognized by Robert Hooke in 1687 (see also Gorham, 1965). From 1855 to 1916, scientists at the Rothamsted Experiment Station in England also demonstrated the relationship between nutrients in air and the growth of various crop plants (Way, 1855; Miller, 1905).

In the mid 1940s an imaginative Swedish soil scientist, Hans Egnér, developed a systematic way to look at the fertilization of crops by nutrients from the atmosphere. Working from his laboratory at the Agricultural College near Uppsala, Egnér created the first 20th-century network for the collection and chemical analysis of precipitation. A large number of sampling buckets were set out at experimental farms all over Sweden, and the major chemical constituents in what we now call bulk deposition (rain, snow, and dust fall) were measured on a regular monthly basis. The acidity of precipitation was one of several chemical parameters that were tested. Other agricultural scientists gradually expanded this network—first to Norway, Denmark, and Finland and later to most of western and central Europe. It came to be called the European Air Chemistry Network and it provided the first large-scale and long-term data on the changing chemistry of precipitation and its importance for agriculture and forestry (Emanuelsson et al. 1954; Egnér et al., 1955). In 1956, the International Meteorological Institute in Stockholm assumed responsibility for further coordination of the network. In 1957, as part of the International Geophysical Year, it spread eastward to include Poland and much of the Soviet Union. In marked contrast to monitoring efforts elsewhere in the world, the original European network with more than 100 collection stations has remained in continuous operation for nearly three decades.

Progress in the atmospheric sciences. Under the imaginative leadership of Carl Gustav Rossby and Erik Eriksson, the science of atmospheric chemistry began in Sweden and later spread across Europe and finally to North America (N.A.S., 1975). Rossby and Eriksson were convinced that atmospheric processes were efficient mechanisms for the long-distance as well as short-distance dispersal of many different substances. The data from Egnér's precipitation chemistry network provided the means to test various hypotheses about the trajectories of air masses, turbulent dispersal processes, and atmospheric scavenging and deposition processes (Rossby and Egnér, 1955). These observations led Eriksson to enunciate a general theory to describe the biogeochemical circu-

Year(s)	Investigator and country	Principal contribution
1957	Europe, U.S.S.R., and U.S.	During the International Geophysical Year, a one-year study of precipitation chemistry was made in Europe, the U.S.S.R., and the U.S.
1958–1959	Junge and Werby, Jordan et al., U.S.	Made the first regional studies of precipitation chemistry in the U.S. and noted the importance of atmospheric sulfur as a source of nutrients for crops (Junge and Werby, 1958; Jordan et al., 1959)
1959	Dannevig, Norway	Recognized the relationship between acid precipitation, acidity in surface waters, and disappearance of fish (Dannevig, 1959)
1960–1963	Gordon and Gorham, Canada	Established that exposure to sulfur dioxide and resultant acid rain contributed to the deterioration of lake quality, vegetation, and soils near metal smelters (Gorham and Gordon, 1960; Gordon and Gorham, 1963)
1960–1966	McCormick, U.S.	Operated the first continent-wide precipitation chemistry network in North America for six years (1960–66). Showed that precipitation is generally acidic east but alkaline west of the Mississippi River (Lodge et al., 1968)
1962	Carson, U.S.	Stimulated a global revolution in environmental awareness by publishing "Silent Spring" in which the term "poison rain" was used to describe concern about atmospheric transport and deposition of pollutants (Carson, 1962)
1967–1968	Odén, Sweden	Outlined the changing acidity of precipitation as a regional and temporal phenomenon in Europe (Odén, 1968, 1976)
		Used trajectory analysis of air masses to demonstrate that acidity in precipitation in Scandinavia was attributable largely to emissions of sulfur in England and central Europe (Odén, 1968)
		Demonstrated temporal trends in acidity and in the concentrations of major cations and anions in precipitation over various parts of Europe (Odén, 1968)
		Demonstrated the increasing acidity of Scandinavian rivers (Odén, 1968)
		Described biological uptake and ion-exchange processes by which natural acidification of soils would be accelerated by atmospheric deposition of ammonia and other cations (Odén, 1968)
		Postulated that acid precipitation would lead to displacement of nutrient cations, reduction in nitrogen fixation, and release of heavy metals (especially Hg) which would damage surface waters and groundwaters (Odén, 1968, 1976)
		Postulated acidity in precipitation as a probable cause of decline in fish populations, impoverishment of forest soils, decreased forest growth, increased disease in plants, and accelerated corrosion and other damage to materials (Odén, 1967, 1968)
1970	Odén and Ahl, Sweden	Discovered that soluble pollutants in snow accumulate in the snow pack and are released almost totally with the first meltwater in spring (Odén and Ahl, 1970)
1970	Hultberg, Sweden	Demonstrated the effect of acidity on fish populations in two Swedish lakes (Hultberg and Stenson, 1970)
1971–1972	Rodhe et al., Sweden	Developed the first quantitative analysis of long-distance transport of sulfur in Europe. Showed that distances of transport frequently exceed 1000 km, the residence time of sulfur in the air is 2–4 days, and fields of deposition are roughly symmetrical and slightly displaced to the northeast from sources of emission (Munn and Rodhe, 1971; Rodhe, 1972)
1972	Bolin et al., Sweden	Drafted Sweden's Case Study for the United Nations Conference on the Human Environment "Air Pollution Across National Boundaries: The Impact on the Environment of Sulfur in Air and Precipitation." Noted damage to materials as well as ecosystems by acid precipitation (Bolin et al., 1972)

lation of matter on the earth (Eriksson, 1952, 1959, 1960).

The transport and deposition of water by atmospheric processes has been well known since the earliest observations of evaporation, cloud movement, and rain. But the notion that atmospheric transport and deposition were a major means for the dispersal and chemical transformation of many other substances was still only a working hypothesis in the early 1950s. Rossby and Eriksson championed these then-novel ideas and initiated various experimental tests of their hypotheses, using as a very powerful tool data from the European Air Chemistry Network. Rossby and Eriksson also sponsored a series of European conferences on atmospheric chemistry and dispersal processes, which attracted the interest of scientists in many other fields of inquiry including biology, forestry, agriculture, meteorology, and medicine (Eriksson, 1954). Both Gorham and Svante Odén were among the students at these conferences, but they never met personally until 1975.

Integration of knowledge

The first major unification of knowledge about acid precipitation in the fields of limnology, agriculture, and atmospheric chemistry was achieved by Odén, a soil scientist at the Agricultural College near Uppsala in Sweden. In 1961, as a young colleague of Egnér, Rossby, and Eriksson, Odén started a Scandinavian network to measure surface water chemistry. When data from this network were combined with those from the European Air Chemistry Network, a series of general trends and relationships began to emerge and were published by Odén in two different media—Stockholm's prestigious newspaper *Dagens Nyheter* (Odén, 1967) and in an Ecology Committee Bulletin (Odén, 1968). The newspaper report outlining Odén's audacious ideas about an insidious "chemical war" among the nations of Europe captured the attention of the press, who began the process of public education about acid precipitation in Europe. In much the same way, the Ecology Committee Bulletin stimulated scientific interest in acid precipitation and its ecological effects. Odén's analyses of air mass trajectories and temporal and geographical changes in precipitation chemistry clearly showed that:

- acid precipitation was a large-scale regional phenomenon in much of Europe with well-defined source and sink regions
- both precipitation and surface

Year(s)	Investigator and country	Principal contribution
1972	Hvatum, Norway	Demonstrated increasing content of lead near the surface of Norwegian peat bogs and postulated long-distance transport as the probable cause (Hvatum, 1972)
1972	Tyler, Sweden	Reported heavy metal accumulation in forest soils and speculated about their probable effects on forest productivity (Tyler, 1972)
1972	Granat, Sweden	Described the temporal and spatial deposition of sulfate and acid over northern Europe (Granat, 1972, 1978)
1972	Jonsson and Sundberg, Sweden	Established an experimental basis for the suspicion that acid precipitation had decreased the growth of forests in Sweden (Jonsson and Sundberg, 1972)
1972	Various agencies, Norway	Initiated the SNSF Project "Acid Precipitation: Effects on Forests and Fish (See *Ambio*, 1976, and Braekke, 1976)
1972–1980	Overrein, Norway	Demonstrated accelerated loss of calcium and other cations from soils receiving acid precipitation (Overrein, 1972)
		Provided leadership for the SNSF Project from its founding in 1972 until its completion in 1980 (*Ambio*, 1976; Overrein et al., 1980; Tollan, 1981)
1972	Likens et al., U.S.	Discussed the regional distribution of acid precipitation and its significance for aquatic and terrestrial ecosystems in North America (Likens et al., 1972)
		Indicated that nitric acid resulting from atmospheric transformation of NO_x adds to the acidity of precipitation in the eastern U.S. (Likens et al., 1972)
1972	Jensen and Snekvik, Norway	Showed that acidity in lakes and streams caused major decreases in salmon and trout populations in Norway (Jensen and Snekvik, 1972)
1972	Beamish and Harvey, Canada	Reported decline in fish populations due to acidification of lake waters in Canada (Beamish and Harvey, 1972)
1972–1980	Various investigators	Showed that mushrooms, mosses, and other vegetation in forests accumulate heavy metals, especially lead and cadmium. Found that wildlife feeding on these plants also accumulate the metals, sometimes making both the plants and the wildlife hazardous for human consumption (Munshower, 1972; Huckabee and Blaylock, 1974; Tyler, 1980)
1973	Malmer, Sweden	Summarized research on the ecological effects of increasing sulfur deposition, especially with reference to Swedish conditions (Malmer, 1973)
1973	Dickson et al., Sweden	Reported on the pH status of 314 lakes in western Sweden (Dickson et al., 1973)
1973	Wiklander, Sweden	Proposed a general theory to account for the effects of acid precipitation on soil chemical properties (Wiklander, 1973)
1973–1977	Ottar, Norway	Led the Organization for Economic Cooperation and Development in Europe in its continent-wide study of the long-range transport of air pollutants (Ottar, 1976; OECD, 1977)
1974	Almer et al., Sweden	Summarized the effects of changing lake water acidity on fish populations in Sweden (Almer et al., 1974)
1974	Grahn et al., Sweden	Discovered that *Sphagnum* (peat moss) invades acidified lakes and streams inducing a self-accelerating oligotrophication of the water body (Grahn et al., 1974)
1974	Cogbill and Likens, U.S.	Published maps showing changes in acidity of precipitation in the eastern U.S. between 1955–56 and 1972–73 (Cogbill and Likens, 1974)
1974	Hutchinson and Whitby, Canada	Established that strongly acid rain near Sudbury, Ontario is accompanied by deposition and/or mobilization of heavy metals (especially nickel, copper, cobalt, iron, aluminum, and manganese). Found toxicity of these metals sufficient to inhibit germination and establishment of many native and agricultural species of plants (Hutchinson and Whitby, 1974; Whitby and Hutchinson, 1974)

waters were becoming more acidic

- long-distance (100–2000 km) transport of sulfur- and nitrogen-containing air pollutants was taking place among the various nations of Europe
- there were marked seasonal trends in deposition of major ions and acidity
- long-term trends in acidity could be detected in many countries of Europe.

Odén also hypothesized that the probable ecological consequences of acid precipitation would be changes in surface water chemistry, decline of fish populations, leaching of toxic metals from soils into surface waters, decreased forest growth, increased plant diseases, and accelerated damage to materials.

These conclusions and hypotheses led to a veritable storm of scientific and public concern about acid precipitation. Suddenly, limnological, agricultural, and atmospheric scientists began to argue and debate with each other about Odén's unconventional ideas and his general theory of atmospheric influences. Multidisciplinary discussions and international conferences ensued all over Europe and around the world as scientist after scientist was inspired (or provoked) into designing experimental tests to prove or to disprove Odén's ideas.

The Swedish government responded to the growing public and scientific controversies by initiating an inquiry that culminated in Sweden's Case Study for the U.N. Conference on the Human Environment: "Air Pollution Across National Boundaries: The Impact of Sulfur in Air and Precipitation" (Bolin et al., 1972).

The important ideas in both the Ecology Committee Bulletin and the Swedish Case Study were debated intensely all over Europe. Two major scientific initiatives followed in short order. The first took place in 1972 when three organizations in Norway joined together to establish the so-called SNSF Project: the Norwegian Interdisciplinary Research Programme "Acid Precipitation – Effects on Forest and Fish." These three organizations included the Norwegian Council for Scientific and Industrial Research, the Agricultural Research Council of Norway, and the Norwegian Ministry of Environment. The annual budget for the SNSF Project was about 10 million Norwegian kroner ($2 million) per year for 1972–1980. This huge project had two comprehensive goals:

- to establish as precisely as possible the effects of acid precipitation on forests and freshwater fish

Year(s)	Investigator and country	Principal contribution
1974	Shriner, U.S.	Demonstrated that simulated rain acidified with sulfuric acid can accelerate erosion of protective waxes on leaves, inhibit nodulation of leguminous plants, and alter host–pathogen interactions of plants (Shriner, 1974, 1976, 1978)
1975	Brosset et al., Sweden	Described the chemical transformations and trajectories that lead to "white episodes" and "black episodes" of acid deposition in western Sweden. Showed that gaseous nitric acid increases acid deposition. Established a state-of-the-art titration method for the determination of acidity in precipitation (Brosset et al., 1975)
1975–1982	Cowling, U.S.	Testified in congressional hearings concerning the inadequacy of research in the U.S. on the ecological effects of acid precipitation (Cowling, 1976)
		Together with many other scientists in the U.S. and Canada, began the development of a permanent network to monitor chemical changes in wet and dry deposition and to study their biological effects in various regions of the U.S. (Galloway and Cowling, 1978)
1975	Cragin, Greenland	Determined the chemistry of precipitation in Greenland from 1300 to 1975 A.D. Found a continuing trend of increasing sulfate and lead concentration beginning about 1800 and rising even more rapidly after 1945. (Cragin et al., 1975)
1976	Schofield, U.S.	Reported the results of lake surveys showing a decline in fish populations associated with acidification of lakes in the Adirondack Mountains of New York State (Schofield, 1976)
1976	Kucera, Sweden	Summarized evidence that acid precipitation accelerates the corrosion of metals (Kucera, 1976)
1976	Summers and Whelpdale, Canada	Summarized earlier studies of precipitation chemistry in Canada and identified northwest Alberta, southern Ontario and Quebec, and the Atlantic Provinces as areas of present or potential impact by acid rain and snow (Summers and Whelpdale, 1976)
1976	Leivestad and Muniz, Norway	Documented a massive fish kill on the Tovdahl River associated with snow melting in the spring of 1975 and established that dead and dying fish had lost control of their blood salt balance. (Leivestad and Muniz, 1976; Leivestad et al., 1976)
1976	Tyler, Sweden	Demonstrated that heavy metals in the litter layer of forests inhibit microbial processes, especially decomposition of organic matter (Tyler, 1976)
1976	Galloway, U.S.; Berry, Canada; Granat, Sweden	Developed standardized protocols for precipitation collectors and collection techniques (Galloway and Likens, 1976; Berry et al., 1976; Granat, 1976)
1976	Hultberg and Grahn, Sweden	Discovered a correlation between acidification of lakes and the mercury content of fish (Hultberg and Grant, 1976)
1976	Pough, U.S.	Showed that reproduction of salamanders is inhibited by acidity of surface waters (Pough, 1976)
1977	Hagström, Sweden	Showed that reproduction of frogs is inhibited by acidity of surface waters (Hagström, 1977)
1977	Rosenqvist Norway	Enunciated a general theory that acidification of soils and surface waters is due mainly to natural processes in soils and to changes in patterns of land use (Rosenqvist, 1977)
1978	Greszta, Austria	Demonstrated accumulation of heavy metals in forest soils leading to injury to young pine and spruce seedlings (Greszta, 1978)
1978–1980	Several investigators, U.S.	Showed that acid precipitation occurs in both urban and certain rural areas in the western U.S. (Liljestrand and Morgan, 1978; McColl and Bush, 1978; Lewis and Grant, 1980)

Year(s)	Investigator and country	Principal contribution
1979	Altshuller, U.S.; McBean, Canada	Documented the transboundary exchange of sulfur and nitrogen oxides between the U.S. and Canada (Altshuller and McBean, 1979)
1979	Odén, Sweden	Showed by studies of surface waters in Sweden that acidification due to sulfur deposition had begun during the early 1900s (Odén, 1979)
1979	Liljestrand and Morgan, U.S.	Completed a rigorous statistical analysis of trends in precipitation chemistry in the eastern and western U.S. (Liljestrand and Morgan, 1979)
1979	Cronan and Schofield, U.S.	Discovered that aluminum ions are leached by acid precipitation from soils into streams and lakes in concentrations toxic to fish (Cronan and Schofield, 1979)
1979	Galloway, U.S.; Whelpdale, Canada	Developed a new sulfur budget for eastern North America and showed that atmospheric sulfur in this region is predominantly of anthropogenic origin (about 95%) and that a substantial fraction (about 30%) of sulfur emissions in this region are deposited outside this region (Galloway and Whelpdale 1979)
1979	Carter, U.S.	Established a presidential initiative on acid rain calling for a 10-year-long, $10 million-per-year interagency program of research on acid precipitation and its environmental consequences in the U.S. (Carter, 1979)
1979	Henriksen, Norway	Developed a simple descriptive model for determining the extent to which acidification decreases the alkalinity of lake waters and applied this method to predict the vulnerability of lakes to acid deposition (Henriksen, 1979
1980	Hultberg and Wenblad, Sweden	Discovered acidification of groundwater in western Sweden, postulated acid precipitation as the probable cause, established by surveys of 1300 wells the frequency of heavy metal accumulation and plumbing problems associated with these wells (Hultberg and Wenblad, 1980)
1980	Abrahamsen, Norway	Summarized many years of research on the effects of acid precipitation on forests and concluded that fertilization effects, particularly by atmospheric deposition of nitrogen, tend to offset nutrient leaching and other detrimental effects. Also emphasized that negative effects of atmospheric deposition on growth are most likely when nutrient deficiencies or imbalances are increased by acid deposition (Abrahamsen, 1980)
1980	Wetstone, U.S.	Summarized the biological and materials damage of acid precipitation in relation to the pollution control laws in North America (Wetstone, 1980)
1980	Schindler et al., Canada	Established an experimental system for controlled acidification of whole lakes (Schindler et al., 1980).
		Demonstrated that acidification eliminated organisms of several trophic levels at pH values as high as 5.8–6.0 (Schindler, 1980). Also demonstrated that microbial reduction of sulfate could partially protect lakes against acidification (Schindler et al., 1980)
1980	Ulrich et al., Germany	Demonstrated a significant correlation between amount of soluble aluminum in forest soils, death of feeder roots in spruce, fir, and birch forests, and widespread decline in the growth of these forests (Ulrich et al., 1980; Schuck et al., 1979)
1980	Various Investigators, U.S.	Established an Integrated Lake Water Acidification Study (ILWAS), to determine detailed chemical budgets for H^+, SO_4^{--}, NH_4^+, NO_3^-, Cl^-, and other ions in three lake watersheds with differing degrees of acidification (see Drablos and Tollan, 1980, pp. 252–267; and EPRI, 1981)
1981	Norton et al., U.S.	Demonstrated by analysis of lake sediments that increased depletion of soil nutrients and increased atmospheric deposition of lead and zinc in northern New England started prior to 1880 (Hanson et al., 1981; Johnston et al., 1981)

- to investigate the effects of air pollutants on soils, vegetation, and water to the extent required to support the primary objective.

Lars Overrein of the Norwegian Forest Research Institute was appointed research director for this project from 1972–1980. The project produced a steady stream of technical and scientific reports on various aspects of acid precipitation and its effects. The SNSF project also sponsored two major international scientific conferences—one at Telemark, Norway, in June 1976 and the second at Sandefjord, Norway, in March 1980. Braekke (1976) and *Ambio* (1976) published major reports in connection with the conference at Telemark. The Sandefjord conference was designed to provide a forum for evaluation not only of recent research within the SNSF Project, but also the large amount of research currently being done elsewhere in the world (Drabløs and Tollan, 1980). A final report and bibliography from the SNSF Project was published at the end of 1980 (Overrein, Seip, and Tollan, 1980; Tollan, 1981).

The second major scientific initiative was conducted by the Organization for Economic Cooperation and Development (OECD) from 1973–1975. This was a study of the long-range transport and deposition of atmospheric sulfur in eastern and western Europe. The OECD findings, published in 1977, showed that the area of acid precipitation included almost all of northwestern Europe. The findings confirmed the idea that pollutants are transported long distances and showed that the air quality in each European country is measurably affected by emissions from all other European Countries (OECD, 1977).

In October of 1977, the Economic Commission for Europe originated the Cooperative Programme for Monitoring and Evaluating the Long-Range Transmission of Air Pollutants in Europe, which is now in operation. The Economic Commission has nearly completed formulating a multinational convention governing nations' responsibilities for combating the long-range transboundary transport of air pollutants. Arne Tollan and Brunjulf Ottar of the SNSF project were commissioned to develop working papers concerning both the atmospheric and biological influences of sulfur in the air and in precipitation.

North American awareness

Concern about acid precipitation and its ecological effects in North America developed first in Canada and then later in the U.S. Initial interests were focused on the effects of sulfur dioxide exposure and associated acid precipitation and heavy metal deposition in the vicinity of metal smelting and sintering operations (Katz, 1939; Gordon and Gorham, 1963), especially those near Sudbury, Ontario—the largest point source of sulfur in the world (Gorham and Gordon, 1960; Hutchinson and Whitby, 1974). During the early 1970s, interest spread to other parts of Canada as declining fish populations were discovered in more and more lakes of southern Ontario and Nova Scotia, remote from local sources of atmospheric sulfur (Beamish and Harvey, 1972). Very early measurements of nitrogen compounds in rain and snow were made by Shutt and Hedley (1925); the first measurements of the pH of precipitation in Canada were reported by Herman and Gorham (1957). A summary of acid precipitation studies in Canada was published in 1976 by Summers and Whelpdale (1976).

The first detailed research on precipitation chemistry in the U.S. was completed by MacIntyre and Young (1923). Emphasis was given to the importance of airborne nutrients for the growth of crops. This work was followed by the work of Junge and other atmospheric scientists during the 1950s (Junge and Werby, 1958). The earliest regional monitoring network for precipitation chemistry was maintained by a group of State Agricultural Experiment Station scientists from 1953–55 (Jordan et al., 1959) and the first national monitoring program was established under the auspices of the Air Pollution Program within the Public Health Service Laboratory at Cincinnati, Ohio. The data for 1960–66 were summarized by Lodge (1968). As has been the case for all such studies in North America, however, these early programs were redirected or terminated so that no continuing records are available of long-term trends in precipitation chemistry.

Scientific and public interest in acid precipitation and its ecological consequences were stimulated in North America by Svante Odén with a series of 14 lectures at various institutions in the U.S. during the fall of 1971, and also by Torsten Ahl and Odén at the 19th International Limnological Congress in Winnipeg, Manitoba, in 1974. A series of publications by Gene Likens, Charles Cogbill, James Galloway, Carl Schofield, and others provided further stimulus (Likens et al., 1972; Likens, 1976; Cogbill and Likens, 1974; Schofield, 1976; Gallo-

Year(s)	Investigator and country	Principal contribution
1981	Rodhe, Sweden; Crutzen, Vanderpol, Sweden	Developed a photochemical model for the formation of sulfuric and nitric acid during long-distance transport. The model shows that the transformation of both of these acids are coupled processes and that their transformation rates and distances of transport are influenced by hydrocarbons and various oxidants in the atmosphere (Rodhe et al., 1981)
1981	Rahn, U.S.	Demonstrated that the Mn/V ratio of aerosols can be used as a tracer to determine the source of acid aerosols in the arctic and suggested its use in determining source–receptor relationships for acid deposition in North America (Rahn, 1981)
Major international conferences documenting further progress		
1950s	Eriksson, Sweden	The International Meteorological Institute sponsored a series of conferences on various aspects of atmospheric chemistry (Eriksson, 1954)
1975–1976	Dochinger and Seliga, U.S.	U.S. Forest Service sponsored the First International Symposium on Acid Precipitation and the Forest Ecosystem at Ohio State University, Columbus, Ohio (Dochinger and Seliga, 1976a, 1976b)
1976	Overrein et al., Norway	SNSF Project and the Norwegian Ministry of the Environment sponsored the International Conference on Effects of Acid Precipitation, Telemark, Norway (Ambio, 1976; Braekke, 1976)
1977	Husar and Lodge, U.S.; Moore, England	The U.N. Environmental Program and several other organizations sponsored an International Symposium on Sulfur in the Atmosphere, Dubrovnik, Yugoslavia (Husar et al., 1978)
1978	Hutchinson, Canada	NATO sponsored an Advanced Research Institute on Ecological Effects of Acid Precipitation in Toronto, Canada (Hutchinson and Havas, 1980)
1978	Howells, England	The Electric Power Research Institute (U.S.) and the Central Electricity Generating Board (Great Britain) sponsored an International Symposium on Ecological Effects of Acid Precipitation (Howells, 1979)
1978	Hendrey, U.S.	U.S. EPA and Brookhaven National Laboratory sponsored an International Workshop on Limnological Aspects of Acid Precipitation, Sagamore Lake, N.Y. (Hendrey, 1978)
1979	Shriner, U.S.	The Oak Ridge National Laboratory sponsored a symposium on the Potential Environmental and Health Effects of Sulfur Deposition, Gatlinburg, Tenn. (Shriner et al., 1980)
1979	Agle, U.S.; Turnbull, Canada	A group of Canadian and U.S. environmental protection organizations sponsored the Action Seminar on Acid Precipitation, Toronto, Canada (Reid, 1980)
1980	Overrein et al., Norway	The SNSF project sponsored an International Conference on Ecological Impacts of Acid Precipitation, Sandefjord, Norway (Overrein et al., 1980; Tollan, 1981)
1980	Miller et al., U.S.	The U.S. Forest Service and other U.S. and international air pollution organizations sponsored an International Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, Riverside, Calif. (Miller, 1980)
1981	Schindler et al., Canada and U.S.	The National Academy of Sciences organized an international committee of scientists to prepare an authoritative overview entitled: "Atmosphere–Biosphere Interactions: Toward a Better Understanding of the Environmental Consequences of Fossil Fuels Combustion." (NAS, 1981)

way and Likens, 1976; Galloway et al., 1978; Likens et al., 1979). Experimental studies of various biological effects of acid precipitation were initiated at Cornell, North Carolina State, and other universities. David Shriner's (1978) dissertation demonstrated both direct injury to vegetation and various indirect effects through pathogens and parasites. Schofield's (1976) research on the extinction of fish populations in the Adirondack Mountains was especially alarming.

Growing awareness of the important impacts of acid precipitation on fish populations and potential effects on forests led the U.S. Forest Service to sponsor the First International Symposium on Acid Precipitation and the Forest Ecosystem in May 1975. The proceedings of this symposium and the associated workshop reports were published by Dochinger and Seliga (1976a, 1976b). At congressional hearings in July 1975, Cowling (1976) testified about the inadequacy of research on acid precipitation in the U.S. Specifically, he said that the lack of coordinated research programs on ecological effects and the absence of a stable monitoring network were the primary causes of the profound ignorance in North America about acid precipitation.

Both Canada and the U.S. have recently started long-term programs for the chemical analysis of precipitation. The Canadian Network for Sampling Precipitation began in 1976; the National Atmospheric Deposition Program was started in the U.S. in 1978 (Galloway and Cowling, 1978). By late 1981, some 50 sampling stations were operating in Canada and 93 in the U.S.

The data from these programs (Figure 1) show that the area receiving acid precipitation now embraces about two-thirds of the total land area of North America. Although sulfuric acid has been found to be the dominant source of acidity both here and in Europe, nitric acid accounts for almost one third, and the fraction is rising.

In 1978, the governments of Canada and the U.S. established a Bilateral Research Consultation Group on the Long-Range Transport of Air Pollutants to coordinate the exchange of scientific information on acid precipitation. This group documented the transboundary flow of air pollutants in eastern North America, and showed that about 11 times more oxides of nitrogen and two to four times more sulfur oxides are transported from the U.S. to Canada than the reverse (Altshuller and McBean, 1979, 1980).

In the late fall of 1978, Congress passed a resolution calling for bilateral discussions with Canada to preserve and protect mutual air resources. A joint statement on the issues was prepared in July 1979, and on Aug. 5, 1980, the governments of Canada and the U.S. signed a Memorandum of Intent to develop a bilateral agreement on transboundary air pollution including "the already serious problem of acid rain." To provide a suitable technical and scientific foundation for the formulation of such an agreement, five bilateral workgroups were established to prepare scientific reports on the following specific aspects of the problem: impact assessment; atmospheric modeling; strategies development and implementation; emissions, costs, and engineering assessments; legal, institutional arrangements; and drafting. Preliminary drafts of the first four of these reports were completed in early 1981 and are presently being refined in preparation for their submission to the Canadian Department of External Affairs and the U.S. Department of State in early 1982.

Coordinated research programs

During the past five years, significant efforts have been made in North America to develop well-coordinated programs of research on both the atmospheric and biological aspects of the acid precipitation problem. In the spring of 1976, a cadre of more than 100 scientists from various state agricultural experiment stations and other federal, state, private university, and industrial research agencies in the U.S. began the process of creating the organization now known as the National Atmospheric Deposition Program (NADP) to meet the need for a coordinated and long-term precipitation chemistry monitoring and effects research program. In mid-1976 the Department of Energy initiated the Multistate Atmospheric Power Production Pollution Study (MAP3S) to improve understanding of the transport, transformation, and fate of pollutants released by energy-related activities.

In the fall of 1977, the President's Council on Environmental Quality contracted with the NADP to draft "A National Program for Assessing the Problem of Atmospheric Deposition (Acid Rain)" (Galloway et al., 1978). This document provided the basis for a presidential initiative on acid precipitation, which former President Carter announced on Aug. 2, 1979, in his Second Environmental Message (Carter, 1979). The presidential initiative called for a 10-year program of research on the causes and consequences of acid precipitation. The Energy Security Act (PL 96-264) passed by Congress in June 1980 provided a legislative mandate for a national effort. Title VII of this act (the Acid Precipitation Act of 1980) also called for development of a National Acid Precipitation Assessment Plan. The purpose was to develop a firmer scientific basis for environmental and energy policy decisions regarding acid precipitation. After extensive interagency discussions, a formal proposal was issued in draft form by the Interagency Task Force on Acid Precipitation (ITFAP, 1981) in January 1981. Title VII also authorized additional financial support from Congress for a comprehensive national program of acid rain research. Leadership for this interagency program was vested with administrators of the National Oceanic and Atmospheric Administration (NOAA), the Department of Agriculture (DOA), and the EPA.

In 1981 the three designated cochairmen were Ferris Webster, an assistant administrator in NOAA; Anson Bertrand, director of the Science and Education Administration at DOA; and Andrew Jovanovich, an acting assistant administrator in EPA. The other agencies comprising the Interagency Task Force included the following: the Council on Environmental Quality (CEQ); the Departments of Commerce (DOC), Energy (DOE), Interior (DOI), State (DOS), and Health and Human Services (DHHS); the National Aeronautics and Space Administration (NASA); the National Science Foundation (NSF); and the Tennessee Valley Authority (TVA).

The National Acid Precipitation Assessment Program is now operational. It is designed as a 10-year-long, multiagency program of policy-oriented research. In the 1982 fiscal year, its cost will be about $18 million. This program is governed by the Federal Interagency Task Force on Acid Precipitation, which sets policy for the national program and oversees its implementation. The task force also has administrative responsibility for federally sponsored efforts and their coordination with ongoing research and monitoring conducted by the states, universities, industry, environmental organizations, and other groups in the U.S., Canada, Mexico, and Europe. The task force will annually report to the president and Congress on the status of knowledge, additional research needs, and alternative strategies for management of acid precipitation and its effects.

TABLE 2

Research tasks in the National Acid Precipitation Assessment Program

Areas and specific tasks	Priority	Leading agency	Participating agencies						Contributing agencies									Start	Duration (years)
			NOAA	DOA	EPA	DOI	DOE	TVA	NOAA	DOA	EPA	DOI	DOE	NSF	TVA	NASA	Other		
Natural Sources		NOAA																	
Assessment of natural sources	High	NOAA	X								X	X	X	X		X		1981	2
Neutralizing materials in the atmosphere	High	NOAA	X							X	X		X	X	X	X		1982	3
Man-made sources		DOE																	
Modeling and economic analysis of emissions	High	DOE			X		X								X			1982	8
Synthesis of emissions data	Medium	DOE			X		X								X			1982	3
Atmospheric processes		NOAA																	
Long-distance transport and dispersion	High	NOAA	X			X					X			X	X	X		1982	5
Global circulation of acid substances	High	NOAA	X				X				X			X		X		1980	6
Aqueous-phase conversion processes	High	NOAA	X	X			X	X			X			X		X		1980	10
Scavenging of gases and aerosols	High	NOAA	X				X				X			X		X		1980	10
Atmospheric modeling	Low	NOAA					X		X		X				X			1981	4
Deposition monitoring		DOI																	
Global and national trends networks	High	DOI	X	X	X	X		X					X					1980	10+
Improving of research networks	High	DOI	X			X	X				X				X			1980	5
Dry deposition measurement methods	High	DOI	X		X		X			X		X						1982	3
Aquatic impacts		EPA																	
State and regional water surveys	High	EPA			X	X									X			1980	4
Modeling lake and stream responses	High	EPA			X	X							X	X	X			1981	5
Tolerance and susceptibility of lakes	High	EPA		X	X	X								X	X			1980	5
Effects on watershed productivity	High	EPA		X	X	X		X					X	X				1980	10
Identification of vulnerable life stages	Medium	EPA				X					X		X	X				1980	5
Mitigation strategies for lakes	Low	EPA		X		X					X				X			1984	5
Acidification of drinking water	High	EPA			X	X											HHS	1980	4
Monitoring drinking water quality	Medium			X	X												HHS	1983	3
Treatment of drinking water	Medium	EPA			X							X						1983	3
Mobilization of toxic metals	Medium	EPA		X	X	X							X					1982	5
Metal contamination of fish	Medium	EPA				X					X	X						1981	2

TABLE 2 (continued)

Research tasks in the National Acid Precipitation Assessment Program

Areas and specific tasks	Priority	Leading agency	Participating agencies						Contributing agencies										Duration
			NOAA	DOA	EPA	DOI	DOE	TVA	NOAA	DOA	EPA	DOI	DOE	NSF	TVA	NASA	Other	Start	(years)
Terrestrial impacts		DOA																	
Effects on growth and productivity of forests	High	DOA		X	X	X		X					X	X				1980	10
Identification of vulnerable life stages	Medium	DOA		X							X		X					1980	10
Effects on plant metabolism	Medium	DOA		X									X	X				1982	5
Effects on forest diseases and insects	High	DOA		X							X							1982	5
Effects on growth and productivity of crops	High	DOA		X	X	X		X					X	X				1980	5
Dose-response relationships of crops	Medium	DOA		X	X								X					1982	5
Effects on crop diseases and insects	Low	DOA		X									X				HHS	1982	5
Metal contamination of crops	Medium	DOA		X									X				HHS	1982	2
Predicting soil vulnerability	High	DOA		X	X	X												1982	3
Effects on soil nutrient status	High	DOA		X	X		X							X	X			1980	5
Effects on soil buffering capacity	High	DOA		X	X							X	X	X	X			1981	5
Mechanisms and amelioration of soil impacts	Low	DOA		X														1982	5
Effects on materials		DOI																	
Effects on construction materials	High	DOI			X	X												1980	5
Costs of materials effects	Medium	DOI			X		X											1984	3
Use of protective coatings	Low	DOI			X	X												1983	3
Control technologies		EPA																	
Development of limestone injection burner	High	EPA			X		X								X			1981	4
Assessments and policy analysis		EPA																	
Computer simulation models	High	EPA			X		X		X									1980	5
Models to guide policy decisions	High	EPA			X		X		X									1980	5
Analysis of emissions dispatching	Medium	EPA			X								X		X			1982	3
Special scientific and policy assessments	High	EPA	X	X	X	X	X							X	X	X	HHS, DOS	1981	10

Table 2 outlines the research efforts in the National Acid Precipitation Assessment Program. Note that a total of 43 specific research tasks are being undertaken. For purposes of coordination and planning, these 43 tasks have been grouped into nine general categories. Research on each specific task and area of scientific work is coordinated by an Interagency Task Group consisting of scientists and program leaders from the relevant member agencies. Each task group functions under the leadership of a representative from one of the eight agencies. The task group leaders for each area of research and their institutional affiliations are listed in Table 3. Chris Bernabo of NOAA has the interagency role of executive director of the task force. He is located at the Council on Environmental Quality and his responsibilities include coordinating the efforts of the nine task groups, overseeing interagency planning, and providing liaison with the task force.

Similarly comprehensive, well-coordinated, and well-funded programs of acid rain research have been initiated by the Province of Ontario and the federal Department of Environment in Canada and by the Electric Power Research Institute in the U.S. Especially noteworthy among these efforts are the Experimental Lakes Studies initiated in northern Ontario by David Schindler et al. (1980) and the Integrated Lake-Watershed Acidification Study sponsored by the Electric Power Research Institute (EPRI, 1981; see also Drabløs and Tollan, 1980, pp. 252-267).

Future research

We have come a long way since the earliest attempts of Smith, Gorham, and Odén to alert the scientific community and the public at large to the causes and consequences of acid rain. Much has been learned both in Europe and in North America. But much more remains to be learned about the many aspects and effects of the phenomenon. The pathway that has led to our present understanding has been illuminated by the remarkable insights of a few imaginative scientists as well as those of many others who have filled lesser voids in our knowledge.

TABLE 3

Task group leaders in the Federal Interagency Task Force on Acid Precipitation

Area	Task group leader
Natural sources	Dr. Daniel Albritton Environmental Research Laboratory National Oceanic and Atmospheric Administration Boulder, Colo.
Man-made sources	Dr. David J. Beecy Office of Fossil Energy U.S. Department of Energy Washington, D.C.
Atmospheric processes	Dr. John Miller Air Resources Laboratory National Oceanic and Atmospheric Administration Silver Spring, Md.
Deposition monitoring	Dr. R. J. Pickering Water Quality Branch U.S. Geological Survey Reston, Va.
Aquatic impacts	Dr. Ray Wilhour Air Pollution Effects Branch Environmental Protection Agency Corvallis, Ore.
Terrestrial impacts	Dr. Leon Dochinger Forestry Sciences Laboratory U.S. Forest Service Delaware, Ohio
Effects on materials	Dr. Ray Herrman Field Support Laboratory National Park Service Fort Collins, Colo.
Control technology	Dr. Kurt Riegel Environmental Engineering and Technology Environmental Protection Agency Washington, D.C.
Assessments and policy	Dr. Lowell Smith Program Integration and Policy Staff Environmental Protection Agency Washington, D.C.

Today, public interest in acid rain research is at an all-time high in many parts of the world. The challenge for us as scientists is to satisfy that curiosity by providing a more extensive understanding of the atmospheric processes, soil transformations, vegetational changes, alterations in water chemistry, effects on materials, and physiological influences of acid precipitation (ITFAP, 1981; NAS, 1981).

Research is the key to improved understanding. Improved understanding is the key to wiser public and private decisions that relate to the use of energy and to the quality of life in our society. Let us get on with the job of learning so that the challenge of managing acid precipitation and its effects can begin as soon as possible.

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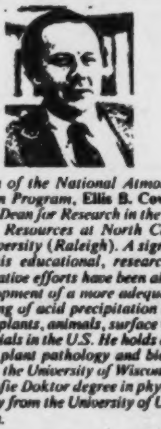

Chairman of the National Atmospheric Deposition Program, **Ellis B. Cowling** *is Associate Dean for Research in the School of Forest Resources at North Carolina State University (Raleigh). A significant part of his educational, research, and administrative efforts have been aimed at the development of a more adequate understanding of acid precipitation and its effects on plants, animals, surface waters, and materials in the U.S. He holds a Ph.D. degree in plant pathology and biochemistry from the University of Wisconsin and the Filosofie Doktor degree in physiological botany from the University of Uppsala in Sweden.*

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Item 7

Acid Precipitation Research Needs

(Taken from the National Acid Precipitation
Assessment Plan - pp. ix - xvi; 118-119)

Research is proposed in nine basic categories (A to I below) where more information about acid precipitation is urgently needed. The research tasks described are each focused on a specific area and generally involve the coordinated participation of several agencies. The number and extent of the proposed research tasks that are eventually carried out will depend on the availability of resources in future years.

Each research task has been assigned one of three priority levels. Priority 1 denotes the most urgently needed research that offers the opportunity for relatively rapid generation of crucial information. Tasks of slightly less urgency are given a priority 2, and priority 3 indicates important research but where the need for results is least urgent.

The research proposed in the Plan is summarized as follows:

A. RESEARCH ON NATURAL SOURCES (Lead Agency - NOAA)

Tasks	Priority	Agencies Participating-	Contributing	Duration
1. Analysis and Assessment of Natural Sources	1	NOAA	- EPA, DOE DOI, NASA NSF	1981-1983
2. Studying Natural Neutralizing Materials in the Atmosphere	1	NOAA	- EPA, DOA DOE, NASA, NSF, TVA	1982-1985

B. RESEARCH ON MAN-MADE SOURCES (Lead Agency - DOE)

	Tasks	Priority	Agencies Participating-Contributing	Duration
1.	Developing Models for Man-Made Emissions and Economic Assessments	1	DOE, EPA - TVA	1982-1990
2.	Synthesizing and Integrating Information on Emission Sources	2	DOE, EPA - TVA	1982-1985

C. RESEARCH ON ATMOSPHERIC PROCESS (Lead Agency - NOAA)

	Tasks	Priority	Participating-Contributing	Duration
1.	Research on Long-Range Transport and Dispersion	1	NOAA, DOI - DOE, EPA NASA, NSF	1982-1987
2.	Determining Global Circulation of Acid Constituents and their Precursors	1	NOAA, DOE - EPA, NASA NSF	1980-1986
3.	Investigating Aqueous-Phase Conversion and Equilibrium Chemistry	1	NOAA, DOE, - EPA, NASA DOA, TVA NSF	1980-1990
4.	Research on Scavenging of Particles and Gases in Clouds	1	NOAA, DOE - EPA, NOAA NSF	1980-1990
5.	Improving Modeling Data Bases	3	DOE - EPA, NOAA, TVA	1981-1985

D. DEPOSITION MONITORING OF ACID SUBSTANCES (Lead Agency - DOI)

	Tasks	Priority	Participating-Contributing	Duration
1.	Further Development of the Global and National Trends Networks	1	DOA, DOI, - DOE EPA, NOAA TVA	1980-1990
2.	Expanding and Improving Research Support Networks	1	DOI, DOE, - EPA, TVA NOAA	1980-1985
3.	Developing Methods for Dry-Deposition Measurements	1	EPA, DOE, - DOA, DOI NOAA	1982-1985

E. RESEARCH ON AQUATIC IMPACTS (Lead Agency - EPA)

	Tasks	Priority	Participating-Contributing	Duration
1.	State and Regional Water Surveys	1	EPA, DOI - TVA	1980-1984

	Tasks	Priority	Agencies Participating-	Contributing	Duration
2.	Modeling of Lakes and Stream Responses	1	DOI, EPA	- DOE, NSF TVA	1981-1986
3.	Determining the Factors that Control the Tolerance and Susceptibility of Lakes	1	DOA, DOI, EPA	- NSF, TVA	1980-1985
4.	Studying Watershed Productivity	1	EPA, DOA, DOI, TVA	- DOE, NSF	1980-1990
5.	Identifying Vulnerable Growth Stages in Aquatic Life	2	DOI	- EPA, DOE,NSF	1980-1985
6.	Analyzing Mitigation Strategies for Acidified Lakes	3	DOI, DOA	- EPA, TVA	1984-1989
7.	Studying Acidification of Drinking-Water Sources	1	EPA,DOI	- HHS	1980-1984
8.	Investigating Metal Contamination in Fish	2	DOI	- EPA, DOI	1981-1983
9.	Monitoring Drinking-Water Systems	2	DOI, EPA	- HHS	1983-1986
10.	Studying the Mobilization of Toxic Metals	2	DOA, DOI, EPA	- DOE	1982-1987
11.	Examining Methods for Treating Acidified Drinking-Water	2	EPA	- DOI	1983-1986

F. RESEARCH ON TERRESTRIAL IMPACTS (Lead Agency - DOA)

Forest Trees and Range Plants

	Tasks	Priority	Participating-	Contributing	Duration
1.	Studying Effects on the Growth and Productivity of Forest Trees and Range Plants	1	DOA, EPA, DOI, TVA	- DOE, NSF	1980-1990
2.	Identifying Vulnerable Growth Stages in Plants	2	DOA	- DOE, EPA	1980-1990
3.	Investigating Effects on Metabolic Functions and Cellular Structure	2	DOA	- DOE, NSF	1982-1987
4.	Analysis of Acid Deposition-Induced Predisposition of Forest and Range Plants to Diseases and Insects	1	DOA	- EPA	1981-1986

Agricultural Crops

		Agencies		
Tasks	Priority	Participating-	Contributing	Duration
5. Studying Growth and Productivity of Major Crops	1	DOA, DOI, EPA, TVA	- DOE, NSF	1980-1985
6. Determining Dose-Response Relationships for Crops	2	DOA, EPA	- DOE	1982-1987
7. Investigating Acid Deposition Induced Predisposition of Crops to Diseases and Insects	3	DOA	- DOE, HHS	1982-1987
8. Analyzing Metal Contamination in Crops	2	DOA	- DOE, HHS	1982-1984

Soils

Tasks	Priority	Participating-	Contributing	Duration
9. Predicting Soil Vulnerability	1	DOA, DOI, EPA	-	1982-1985
10. Studying Effects on the Ability of Soils to Support Vegetation	1	DOI, EPA,	- NSF, TVA	1980-1985
11. Analyzing the Buffering Capacity and Response of Soils to Acid Deposition	1	DOA, EPA	- DOI, DOE, NSF, TVA	1981-1986
12. Analyzing Soil Degradation Mechanisms and Mitigation Measures	3	DOA	-	1982-1987

G. RESEARCH ON MATERIALS (Lead Agency - DOI)

Tasks	Priority	Participating-	Contributing	Duration
1. Determining Effects on Construction Materials	1	DOI, EPA	-	1980-1985
2. Estimating the Costs of Materials Damages.	2	EPA, DOE	-	1984-1987
3. Research on Protective Coatings and Treatments	3	DOI, EPA	-	1983-1986

H. RESEARCH ON CONTROL TECHNOLOGIES (Lead Agency - EPA)

	Tasks	Priority	Participating-	Contributing	Duration
1.	Development of the Limestone Injection/Multistage Burner	1	EPA, DOE	- TVA	1981-1985

I. ASSESSMENTS AND POLICY ANALYSIS (Lead Agency - EPA)

	Tasks	Priority	Participating-	Contributing	Duration
1.	Improving Computer Simulation Capabilities	1	EPA, DOE	- NOAA	1980-1985
2.	Model Applications to Guide Policy Decisions	1	EPA, DOE	- NOAA	1980-1985
3.	Analyzing the Benefits and Costs of Emission-Oriented Electrical Generation	2	EPA,	- DOE, TVA	1982-1984
4.	Preparing Special Scientific Information and Policy Assessment Documents	1	DOA, DOE,DOI-EPA, NOAA	DOS, HHS, NASA, NSF, TVA	1981-1990

Organization and Implementation

The Interagency Task Force on Acid Precipitation is jointly chaired by the Department of Agriculture (DOA), the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). The other participating Federal entities are: The Council on Environmental Quality (CEQ), the Departments of Commerce (DOC); Energy (DOE); Interior (DOI); State (DOS); and Health and Human Services (DHHS); the National Aeronautics and Space Administration (NASA); the National Science Foundation (NSF); and the Tennessee Valley Authority

(TVA). The Task Force also will include four Presidential appointees and the Directors of Argonne National Laboratory, Brookhaven National Laboratory, Oak Ridge National Laboratory and the Pacific Northwest National Laboratory.

The main responsibilities of the Task Force are to:

- Provide policy guidance for the National Program;
- Develop and update the National Acid Precipitation Assessment Plan;
- Oversee and implement the ten-year comprehensive program;
- Coordinate the activities of the Federal agencies;
- Maintain an inventory of Federally-funded acid precipitation research projects;
- Develop and submit interagency budgetary analyses;
- Provide annual reports on the program's progress and policy implications;
- Encourage productive interaction between the Federal program and private sector, academic, State and local governmental and international activities;

- o Obtain non-Federal input to the planning and program activities.

The individual agencies will manage and operate their own projects, but these efforts will be carried out in the context of the National Program defined by the current ten-year Plan and with oversight by the Task Force.

Lead agencies for each of the nine research categories (A to I above) will oversee and facilitate detailed planning of activities in their assigned areas. Lead agencies will chair interagency working groups for each research category.

The Task Force will produce an interagency budgetary analysis for the National Program each fiscal year. Early in the budget cycle, the Task Force will advise each agency on the implications of the National Plan for its program directions and budget. When submitting budget requests to the Office of Management and Budget (OMB), the agencies will specifically indicate the programs that the Task Force has agreed will represent their portion of the National Program. OMB will review the requests of the various agencies' acid precipitation activities as being part of a coherent multiagency program.

The Task Force will maintain a working group on international cooperation. This group will be chaired by the Department of State and will be responsible for ensuring that the U.S. National Acid Precipitation Assessment Program is supportive of, and coordinated with, the relevant international activities.

5. Lead Agencies

A lead agency has been designated by the Task Force for each of the research categories listed in Parts III and IV as section A through I.

Research Category	Lead Agency
A. Natural Sources	NOAA
B. Man-made Sources	DOE
C. Atmospheric Processes	NOAA
D. Deposition Monitoring of Acid Substances	DOI
E. Aquatic Impacts	EPA
F. Terrestrial Impacts	DOA
G. Effects on Materials	DOI
H. Control Technologies	EPA
I. Assessments and Policy Anaylsis	EPA

Lead agencies will coordinate interagency planning and implementation of the efforts in their assigned areas. Various other agencies will continue to conduct their own programs in each area as appropriate. While designation as lead agency does not necessarily indicate either a dominant role or the highest level of activities in the assigned category, it does involve responsibility in the assigned category for:

- Overseeing and facilitating detailed program planning and preparation of a detailed planning document;

- Providing the Task Force with assessments of progress in attaining goals described in the National Plan;
- Coordinating interagency flow of budget and program information to the Task Force;
- Supplying input and assistance for plan revisions, annual reports and the interagency budget analyses;
- Coordination with non-Federal groups and activities and assuring the solicitation of input from such groups;
- Encouraging and establishing interagency cooperation in the assigned area;
- Chairing an interagency working group to plan and review activities in the assigned research category.

C. PLANNING AND IMPLEMENTATION

The Task Force will meet at least twice a year and as necessary to ensure adequate administration of the program. A summer meeting will be held to review the progress of the program, to determine future priorities, to plan for the annual report for the current year and to provide guidance for the preparation of the interagency budget analysis for the following fiscal year. In the winter, a second meeting will be held to approve the annual report, to examine the current fiscal year programs and to plan for the next budget cycle.

Item 8

Table 1. Responsibilities of Federal Agencies in Relation to Acid Precipitation

Agency	Primary Areas of Responsibilitity and Expertise
Department of the Interior: (Water Resources Division's Research and Federal/State Cooperative Programs, National Water-Quality Laboratories, Office of Water Data Coordination, National Water Data Exchange.)	-Influence of atmospheric deposition on quality of surface water and ground water. -Hydrologic transport and geochemistry -Monitoring of precipitation quality -Analytical methods and quality assurance for analysis of atmospheric deposition samples -Availability of water data
Fish and Wildlife Service	-Health and stability of aquatic life with emphasis on fish and wildlife (also assigned to USDA Forest Service)
National Park Service	-Preservation, protection, aesthetic quality of the natural and historical resources of the National Park System
Bureau of Land Management	-Forest growth and range resources on BLM lands
Department of Energy: (Office of Health and Environmental Research through national laboratories and university research projects.)	-Atmospheric emissions from power plants -Chemical transformation of pollutants in the atmopshere -Environmental transport and biogeochemistry -Quality assurance in precipitation chemistry data -Ecological effects of pollutants resulting from energy production -Environmental assessment of fossill energy technologies
Tennessee Valley Authority: (Office of Natural Resources and Office of Power.)	-Development and demonstration of emission control technologies for combustion of fossil-fuels and advanced energy technologies -Development and demonstration of technology for integrated management and conservation of land, air, and water resources on the Tennessee Valley region -Local and regional monitoring of impacts of energy production and other sources of pollution on air quality, water quality, land use, soils, and biota of the Tennessee Valley -Research, model development, and model application for dispersion, and regional and interregional transport, transformation, fate, and effects--both terrestrial and aquatic--of energy-related pollutants and interaction of these and pollutants from other sources
Department of Commerce: National Oceanic and Atmospheric Association (National Weather Service, Environmental Data Service, Environmental Research Laboratories, and universities.)	-Precipitation as related to weather and river forecasting -Geophysical monitoring for climate change -Maintaining base line stations for the World Meterological Organization.

Table 1. Continued

Department of Agriculture:	
Agricultural Research (Federal research scientists at cooperating State Agricultural Experiment Stations.)	-Air pollution effects on vegetation -Productivity and stability of soils -Nutrient cycling and fertilization of agricultural ecosystems -Hydrology of agricultural lands -Emissions from intensive agricultural operations
Forest Service (Regional Forest Experiment Station.)	-Air pollution effects on forests -Nutrient cycling in forest ecosystems -Hydrology of forest lands -Productivity of forests and range lands -Stability of wildlife and fish populations -Emissions from wildfires and intensive forest operations
National Science Foundation: (Division of Atmospheric Sciences, Division of Advanced Environmental Research and Technology, Division of Environmental Biology.)	-Weather modification -Atmospheric cycling of organic and inorganic compounds -Identification of sources and sinks and description of chemical mechanisms for substances in the atmosphere -Effects of atmospheric deposition on biota -Definition of sulfur and nitrogen cycles in natural and managed systems -Watershed and total system studies, including development of mathematical and simulation models of nutrient flux and productivity
Environmental Protection Agency:	
(Environmental Monitoring Systems Laboratory, Environmental Sciences Research Laboratory, Health Effects Research Laboratory, Ecological Research Laboratory and university research contracts.)	Monitoring and Measurements -Analytical methods, instrumentation, quality assurance for monitoring gases, aerosols, particulate matter, and precipitation -Support and analyses of EPA/NOAA/WMO deposition network -Maintenance of an acid precipitation data bank Effects and Impacts -Areas in the U.S. sensitive to acidic deposition -Effects of acid deposition on lake-watershed ecosystems -Trace metal concentrations and speciation in lakes -Effects on microbial decomposition -Thresholds for physiological damage from single and combined doses of SO_2, O_3, and NO_2 -Interactions of acid deposition with other pollutants -Scope of acid depositional impacts on drinking water systems -Economic assessment methodologies for long-term effects of acid rain on natural resources

Table 1. Continued

	Transport and Transformation -Modeling -Gas and liquid phase chemical kinetics -Field measurements of single source and area source plume transmission -Dry deposition parameterization Materials Effects -Erosion rates of stone monuments
National Aeronautics and Space Administration: (Biomedical Office of Kennedy Space Center and the Earth Resources Satellite Program.)	-Emissions from combustion of rocket fuels and their effects of ecosystems, materials and human health -Use of remote sensing to detect environmental stress in plants
Department of State: (Office of Environmental Affairs.)	-Transboundary exchange of air pollutants with Canada -International science development efforts
State Agricultural Experiment Stations: (State-Federal cooperative research on agriculture and forestry at 56 State Universities and Land-Grant Colleges)	-Air pollution effects on vegetation -Wind-erosion, formation, productivity, and nutrient status of soils. -Effects of acid precipitation on plant host-parasite interactions. -Nutrient cycling and fertilization of agricultural ecosystems. -Leaching of nutrients from foliage and the root zone of plants. -Development of the North Central Regional Project on Atmospheric Deposition -- NC-141.

Item 9

Memorandum of Intent between the Government of Canada and the Government of the United States of America concerning Transboundary Air Pollution

On August 5, 1980 Canada and the United States took an important step toward dealing with acid rain and other forms of air pollution crossing the border with the signature of the Memorandun of Intent. In this document the two governments recognized the urgency of protecting the environment from damage being caused by transboundary air pollution. They express the conviction that the best means to do so would be cooperative action to achieve necessary reductions in pollution levels.

2. In preparing the way for a bilateral agreement, the Memorandum establishes five technical work groups to assist negotiations. The work groups will have the following principal responsibilities:

- The Impact Assessment Work Group will provide information on the current and projected impact of air pollutants on sensitive receptor areas.
- The Atmospheric Modelling Work Group will carry out cooperative atmospheric modelling to improve understanding of the transport of air pollutants between source regions and sensitive areas.
- The Strategies Development and Implementation Work Group will identify, assess and propose alternatives for controlling emissions.
- The Emissions, Costs and Engineering Assessment Sub-Group will provide support to the Strategies Group. It will do so by identifying control technologies, detailing historical emission trends, and projecting future emission rates from defined source regions.
- The Legal, Institutional and Drafting Work Group will develop legal elements of an agreement and propose institutional arrangements needed to give it effect.

The Work Groups will undertake the necessary technical preparations for negotiations and will report to a bilateral coordinating committee.

3. The Memorandum also calls upon both Governments to take interim actions under current authority to combat transboundary air pollution.

Memorandum of Intent between the Government of Canada and the Government of the United States of America concerning Transboundary Air Pollution

The Government of Canada and the Government of the United States of America,

Share a concern about actual and potential damage resulting from transboundary air pollution, (which is the short and long range transport of air pollutants between their countries), including the already serious problem of acid rain;

Recognize this is an important and urgent bilateral problem as it involves the flow of air pollutants in both directions across the international boundary, especially the long range transport of air pollutants;

Share also a common determination to combat transboundary air pollution in keeping with their existing international rights, obligations, commitments and cooperative practices, including those set forth in the 1909 Boundary Waters Treaty, the 1972 Stockholm Declaration on the Human Environment, the 1978 Great Lakes Water Quality Agreement, and the 1979 ECE Convention on Long Range Transboundary Air Pollution;

Undertook in July 1979 to develop a bilateral cooperative agreement on air quality which would deal effectively with transboundary air pollution;

Are resolved as a matter of priority both to improve scientific understanding of the long range transport of air pollutants and its effects and to develop and implement policies, practices and technologies to combat its impact;

Are resolved to protect the environment in harmony with measures to meet energy needs and other national objectives;

Note scientific findings which indicate that continued pollutant loadings will result in extensive acidification in geologically sensitive areas during the coming years, and that increased pollutant loadings will accelerate this process;

Are concerned that environmental stress could be increased if action is not taken to reduce transboundary air pollution;

Are convinced that the best means to protect the environment from the effects of transboundary air pollution is through the achievement of necessary reductions in pollutant loadings;

Are convinced also that this common problem requires cooperative action by both countries;

Intend to increase bilateral cooperative action to deal effectively with transboundary air pollution, including acid rain.

In particular, the Government of Canada and the Government of the United States of America intend:

1. to develop a bilateral agreement which will reflect and further the development of effective domestic control programs and other measures to combat transboundary air pollution;
2. to facilitate the conclusion of such an agreement as soon as possible; and,
3. pending conclusion of such an agreement, to take interim actions available under current authority to combat transboundary air pollution.

The specific undertakings of both Governments at this time are outlined below.

Interim Actions

1. *Transboundary Air Pollution Agreement*

Further to their Joint Statement of July 26, 1979, and subsequent bilateral discussions, both Governments shall take all necessary steps forthwith:

(a) to establish a Canada/United States Coordinating Committee which will undertake preparatory discussions immediately and commence formal negotiations no later than June 1, 1981, of a cooperative agreement on transboundary air pollution; and

(b) to provide the necessary resources for the Committee to carry out its work, including the working group structure as set forth in the Annex. Members will be appointed to the work groups by each Government as soon as possible.

2. *Control Measures*

To combat transboundary air pollution both Governments shall:

(a) develop domestic air pollution control policies and strategies, and as necessary and appropriate, seek legislative or other support to give effect to them;

(b) promote vigorous enforcement of existing laws and regulations as they require limitation of emissions from new, substantially modified and existing facilities in a way which is responsive to the problems of transboundary air pollution; and

(c) share information and consult on actions being taken pursuant to (a) and (b) above.

3. *Notification and Consultation*

Both Governments shall continue and expand their long-standing practice of advance notification and consultation on proposed actions involving a significant risk or potential risk of causing or increasing transboundary air pollution, including:

(a) proposed major industrial development or other actions which may cause significant increases in transboundary air pollution; and

(b) proposed changes of policy, regulations or practices which may significantly affect transboundary air pollution.

4. *Scientific Information, Research and Development*

In order to improve understanding of their common problem and to increase their capability for controlling transboundary air pollution both Governments shall:

(a) exchange information generated in research programs being undertaken in both countries on the atmospheric aspects of the transport of air pollutants and on their effects on aquatic and terrestrial ecosystems and on human health and property;

(b) maintain and further develop a coordinated program for monitoring and evaluation of the impacts of transboundary air pollution, including the maintenance of a Canada/United States sampling network and exchange of data on current and projected emissions of major air pollutants; and

(c) continue to exchange information on research to develop improved technologies for reducing emissions of major air pollutants of concern.

The Memorandum of Intent will become effective on signature and will remain in effect until revised by mutual agreement.

DONE in duplicate at Washington, this fifth day of August, 1980, in the English and French languages, both texts being equally authoritative.

FOR THE GOVERNMENT OF CANADA:	FOR THE GOVERNMENT OF THE UNITED STATES OF AMERICA:

ANNEX

Work Group Structure
for
Negotiation of a
Transboundary Air Pollution
Agreement

I. *Purpose*

To establish technical and scientific work groups to assist in preparations for and the conduct of negotiations on a bilateral transboundary air pollution agreement. These groups shall include:

1. Impact Assessment Work Group
2. Atmospheric Modelling Work Group

3A. Strategies Development and Implementation Work Group

3B. Emissions, Costs and Engineering Assessment Subgroup

4. Legal, Institutional Arrangements and Drafting Work Group

II. *Terms of Reference*

A. General

1. The Work Groups shall function under the general direction and policy guidance of a Canada/United States Coordinating Committee co-chaired by the Department of External Affairs and the Department of State.

2. The Work Groups shall provide reports assembling and analyzing information and identifying measures as outlined in Part B below, which will provide the basis of proposals for inclusion in a transboundary air pollution agreement. These reports shall be provided by January 1982 and shall be based on available information.

3. Within one month of the establishment of the Work Groups, they shall submit to the Canada/United States Coordinating Committee a work plan to accomplish the specific tasks outlined in Part B, below. Additionally, each Work Group shall submit an interim report by January 15, 1981.

4. During the course of negotiations and under the general direction and policy guidance of the Coordinating Committee, the Work Groups shall assist the Coordinating Committee as required.

5. Nothing in the foregoing shall preclude subsequent alteration of the tasks of the Work Groups or the establishment of additional Work Groups as may be agreed upon by the Governments.

B. Specific

The specific tasks of the Work Groups are set forth below.

1. *Impact Assessment Work Group*

The Group will provide information on the current and projected impact of air pollutants on sensitive receptor areas, and prepare proposals for the "Research, Modelling and Monitoring" element of an agreement.

In carrying out this work, the Group will:

- identify and assess physical and biological consequences possibly related to transboundary air pollution;
- determine the present status of physical and biological indicators which characterize the ecological stability of each sensitive area identified;
- review available data bases to establish more accurately historic adverse environmental impacts;
- determine the current adverse environmental impact within identified sensitive areas—annual, seasonal and episodic;
- determine the release of residues potentially related to transboundary air pollution, including possible episodic release from snowpack melt in sensitive areas;
- assess the years remaining before significant ecological changes are sustained within identified sensitive areas;
- propose reductions in the air pollutant deposition rates—annual, seasonal and episodic—which would be necessary to protect identified sensitive areas; and
- prepare proposals for the "Research, Modelling and Monitoring" element of an agreement.

2. *Atmospheric Modelling Work Group*

The Group will provide information based on cooperative atmospheric modelling activities leading to an understanding of the transport of air pollutants between source regions and sensitive areas, and prepare proposals for the "Research, Modelling and Monitoring" element of an agreement. As a first priority the Group will by October 1, 1980 provide initial guidance on suitable atmospheric transport models to be used in preliminary assessment activities.

In carrying out its work, the Group will:

- identify source regions and applicable emission data bases;
- evaluate and select atmospheric transport models and data bases to be used;
- relate emissions from the source regions to loadings in each identified sensitive area;
- calculate emission reductions required from source regions to achieve proposed reductions in air pollutant concentration and deposition rates which would be necessary in order to protect sensitive areas;
- assess historic trends of emissions, ambient concentrations and atmospheric deposition trends to gain further insights into source receptor relationships for air quality, including deposition; and
- prepare proposals for the "Research, Modelling and Monitoring" element of an agreement.

3A. *Strategies Development and Implementation Work Group*

The Group will identify, assess and propose options for the "Control" element of an agreement. Subject to the overall direction of the Coordinating Committee, it will be responsible also for coordination of the activities of Work Groups I and II. It will have one subgroup.

In carrying out its work, the Group will:

- prepare various strategy packages for the Coordinating Committee designed to achieve proposed emission reductions;
- coordinate with other Work Groups to increase the effectiveness of these packages;

- identify monitoring requirements for the implementation of any tentatively agreed-upon emission-reduction strategy for each country;
- propose additional means to further coordinate the air quality programs of the two countries; and
- prepare proposals relating to the actions each Government would need to take to implement the various strategy options.

3B. *Emissions, Costs and Engineering Assessment Subgroup*

This Subgroup will provide support to the development of the "Control" element of an agreement. It will also prepare proposals for the "Applied Research and Development" element of an agreement.

In carrying out its work, the Subgroup will:

- identify control technologies, which are available presently or in the near future, and their associated costs;
- review available data bases in order to establish improved historical emission trends for defined source regions;
- determine current emission rates from defined source regions;
- project future emission rates from defined source regions for most probable economic growth and pollution control conditions;
- project future emission rates resulting from the implementation of proposed strategy packages, and associated costs of implementing the proposed strategy packages; and
- prepare proposals for the "Applied Research and Development" element of an agreement.

4. *Legal, Institutional and Drafting Work Group*

The Group will:

- develop the legal elements of an agreement such as notification and consultation, equal access, non-discrimination, liability and compensation;
- propose institutional arrangements needed to give effect to an agreement and monitor its implementation; and
- review proposals of the Work Groups and refine language of draft provisions of an agreement.

Canadä

Published by Authority of the
Honourable Mark MacGuigan,
Secretary of State for External Affairs,
Government of Canada

External Affairs
Canada

Affaires extérieures
Canada

Item 10

PRELIMINARY DRAFT OF A CONCEPTUAL PLAN FOR MANAGEMENT OF ACID PRECIPITATION AND ITS EFFECTS ON AQUATIC ECOSYSTEMS IN THE EASTERN UNITED STATES AND CANADA

The Scientific Foundation for a Management Plan

Atmospheric deposition of strong acids and associated accumulation of toxic metals in surface waters are now widely recognized as significant causes of detrimental effects on water quality and aquatic life in sensitive lakes, streams and certain rivers in various parts of the eastern United States and southeastern Canada (see Figure 1 and NAS, 1981). Regions of greatest sensitivity to acid precipitation usually are recently glaciated, with large areas of exposed granitic (crystalline) and other non-calcarious bedrock and thin soils that are poorly buffered and have low cation exchange capacity (Reuss, 1975). These sensitive surface waters are found mainly in the following states of the eastern United States:

> New York, Massachusetts, New Hampshire, Vermont, Maine, Pennsylvania, New Jersey, West Virginia, Maryland, Virginia, North Carolina, Tennessee, South Carolina, Georgia, Alabama, Michigan, Wisconsin, and Minnesota;

and the following Provinces of eastern Canada:

> Ontario, Quebec, Nova Scotia, and New Foundland (see Figure 2 and Galloway and Cowling, 1978).

Important biological and chemical effects of atmospheric deposition on water quality and fish populations have been reported in the following states:

> New York, Massachusetts, New Hampshire, Maine, Pennsylvania, West Virginia, North Carolina, Tennessee;

and the following Provinces of Canada;

> Ontario, Quebec, and Nova Scotia (Galloway, 1981).

National Atmospheric Deposition Program
Annual Average pH - 1980
NADP & CANSAP Data
March 1982

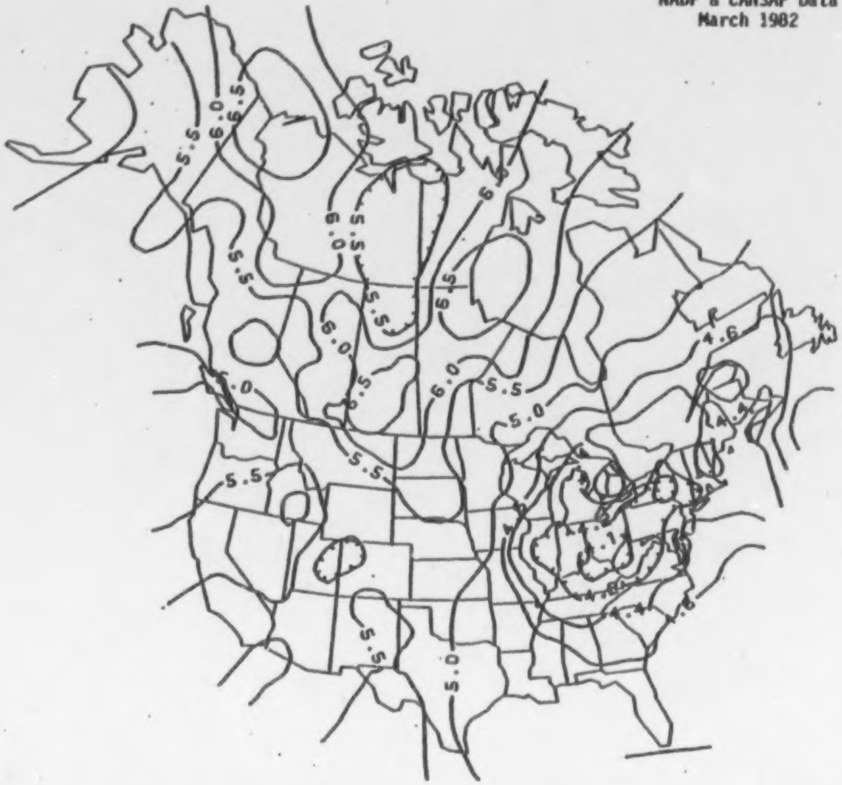
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Figure 1

CONTOUR MAP OF PRECIPITATION WEIGHTED PH
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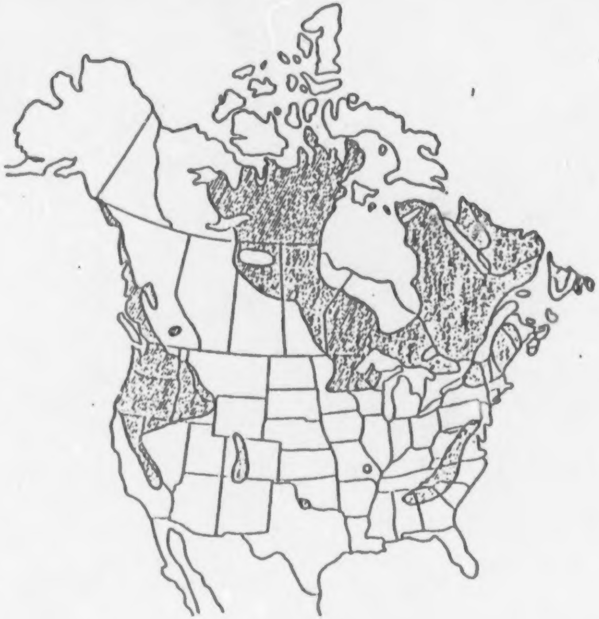

Figure 2. Regions of North America (shaded) containing lakes sensitive to acidification (from Galloway and Cowling 1978).

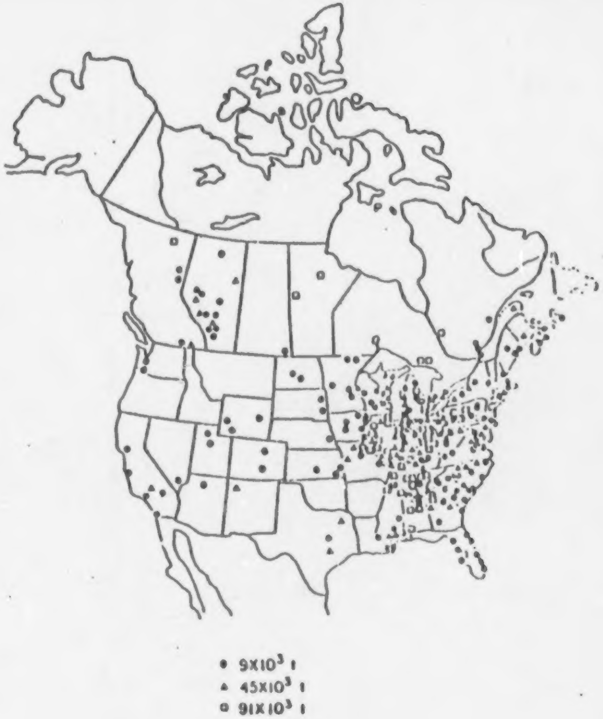
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Figure 3. Annual sulfur dioxide emissions in North America (from Graves 1980).

The principal cause of these detrimental effects on sensitive surface waters are man-made emissions of sulfur and nitrogen oxides from combustion of fossil fuels (principally coal and oil) in the following types of public and private facilities ([illegible], 1981):

1) Electric power generating plants
2) Metal smelters
3) Industrial boilers
4) Transportation vehicles
5) Furnaces and boilers in residential and commercial buildings

Figure 3 shows the regional distribtion of major sources of sulfur dioxide in the United States and Canada (Graves, 1980). The major sources of nitrogen oxides show an approximately similar distribution pattern in the eastern United States and provinces of Canada.

Sulfur dioxide, nitrogen oxides, toxic metals, and other volatile waste products are emitted from these facilities in all seasons of the year. These substances and their reaction products are dispersed in all directions by wind, by turbulent mixing, and other meteorological processes, and finally are deposited on the landscape and in surface waters as gases, fine aerosol and coarse particles, and dissolved or suspended substances in rain, snow, or frost (Husar and Patterson, 1980). These deposition processes occur continuously -- wet deposition occurring during all rain and snow storms and dry deposition occurring whenever it is not raining or snowing (Bolin et al., 1972).

The fields of waste-product deposition from the various facilities listed above typically extend hundreds or even a thousand miles or more from the original source of emission (Likens et al., 1979; see also Figures 2 and 3). Thus, the chemical composition of atmospheric deposition within each state or province in eastern North America is a function of all the air-borne substances dispersed, *mixed, transformed, and transported into the atmosphere and deposited on the land and surface waters of that state or province (NAS, 1981).*

Atmospheric deposition of acid substances can also mobilize both plant nutrients and toxic metals from soils and carry them from the soil into ground water, streams, and lakes, where they accumulate in the surface waters, ground waters, bottom sediments, fish, fish food organisms, and other parts of aquatic ecosystems (Odén, 1976; Schofield, 1976).

Wind speed, wind direction, and other meteorological forces over the eastern United States and Canada are highly variable from month to month and season to season of the year. Also, the time period between emission to the atmosphere and deposition in the earth's surface is typically two to five days for both sulfur and nitrogen oxides. Thus, the residence time of air pollutants in the atmosphere is sufficient for long-distance as well as short-distance transport of acid substances, toxic metals, and other volatile waste products (Wilson et al., 1981; Husar and Patterson, 1980; Rodhe, 1981).

The minimum time period of *deposition* which leads to the most significant changes in water quality and populations of fish and other living things in surface waters is of the order of many weeks, several months, or even several years of time (Schofield, 1976; Odén, 1976). Thus, the well-established patterns of seasonal and annual variability in wind speed and direction, amount of rain and snow, and periods of wet and dry deposition (with or without rain or snow), can be used to provide reasonable estimates of the *biologically important* transport and deposition of nutrient substances, strong acids, and other toxic substances from the atmosphere (Rodhe, 1972). These same well-established patterns of *regional climatology* can be used to estimate the biologically important interstate and international transport of acidifying and toxic substances (Rodhe, 1981; Wilson et al., 1981). For all of the above reasons, it follows that *atmospheric emissions of sulfur dioxide, nitrogen oxides, toxic metals, and other volatile* waste production in all states of the eastern United States and in all provinces of eastern Canada contribute to the deposition and accumulation of strong acids and other toxic substances in each of the major sensitive regions of eastern North America. This geographical relationship is demonstrated by comparing the major areas of sulfur dioxide (and nitrogen oxide) emission (see Figure 3) with the major regions that are sensitive to acid deposition shown in Figure 2. It is also demonstrated by comparing the distribution of sources in Figure 3 with the areas now receiving precipitation with an average annual acidity of less than pH 4.6 as shown in Figure 1.

Alternative Strategies of Management

The evidence summarized very briefly in the above paragraphs suggests that a biologically, chemically, and climatologically sound plan of management for acid precipitation and its ecological consequences can be developed for the eastern United States and Canada. Three alternative management strategies have been suggested:

1) Decrease the amount of emissions leading to acid deposition;
2) Use ameliorative treatments such as liming of watersheds or lakes and streams or controlled additions of alkaline materials to municipal reservoirs; or,
3) Develop acid-tolerant forms of aquatic life including both fish and fish-food organisms.

Assuming that alternative 1 (above) is the alternative plan of choice, as suggested in the recent Atmosphere-Biosphere Report of the National Academy of Sciences, emissions of sulfur and nitrogen oxide should be decreased by an amount sufficient to maintain the average annual acidity of precipitation above pH 4.6 or 4.7 (NAS, 1981). This estimate of a biologically acceptable acidity of precipitation is based on surveys of fish populations in acidified, partially acidified, and non-acidified lakes and streams in Europe and North America

(Henriksen, 1980; Dickson et al., 1973; Schofield, 1976). This estimate involves the assumption that wet and dry deposition make approximately equivalent contributions to the total loading of strong acids and acidifying substances from the atmosphere. This assumption appears reasonable over most sensitive regions of the eastern United States and Canada (see Figure 2).

Some uncertainty exists about the exact relationship between the extent of decrease in emissions that would be required to achieve a given percentage decrease in deposition in sensitive regions. Uncertainty about the equivalence between decreases in emissions and decreases in deposition is generally regarded to be low for dry deposition but may be substantial for wet deposition of strong acids and other acidifying substances.

Very encouraging evidence that useful improvement in air and water quality can be achieved by decreases in sulfur oxide emissions in the eastern United States and Canada is provided by two recent observations:

1) Improvement in summertime visibility due to decreased haziness of the atmosphere in the eastern United States between 1975 and 1980 (Bachmann, 1981); and
2) Decreased acidity and associated improved fish stocks in Nova Scotia rivers between the mid 1970s and 1980-81 (Loucks, 1981).

The Issues of Economic and Political Equity

Sound decisions about management procedures for improvement of air and water quality invariably require judgements under conditions of uncertainty and involve complex assessments of public attitudes and values, scientific certainty, and political and economic equity. The relevant issues in any management decision regarding acid precipitation include assessment of public attitudes toward natural resources, water and air quality, as well as regional, national, and international estimates of economic, aesthetic, and social costs and benefits.

On the assumption that an adequate desire to protect sensitive lakes, streams, and aquatic life exists in the United States Congress, in the Parliament of Canada, and in the relevant states and provinces of the two countries, the following proposal is offered as one possible plan for management of acid precipitation and its effects on aquatic ecosystems in the eastern United States and Canada.

As indicated earlier, emissions in all eastern states of the United States and all eastern provinces of Canada contribute to the deposition of strong acids and toxic metals in each of the sensitive regions in the eastern part of the continent. Thus, in the interest of good neighborliness and out of respect for the rights of persons in other states and provinces, the people of each state and province may be agreeable to doing their part to achieve the general decrease in emissions that would be required to protect sensitive aquatic resources. This would mean that each state and province would decrease their total emissions of both sulfur and nitrogen oxides. In the interest of economic equity an equal percentage decrease in emissions would be expected of each state and province. This will distribute the costs across all relevant states and provinces in direct proportion to their contribution to total emissions. In order to give appropriate credit for past success in decreasing emissions of sulfur and nitrogen oxides, the amount of decrease expected of each state and province could be calculated on the basis of changes in emissions of both major pollutants over the past several years. One possible date on which to base these calculations might be the dates on which the United States and Canadian Clean Air Acts were passed.

The questions of how large a percentage decrease in emissions could be achieved and the time span over which these emissions might be scheduled involve questions of public will as well as both political and technological feasibility. Total emissions of sulfur dioxide in the relevant states and provinces were approximately 24 million tons in 1980. As a basis for initial discussion, it is proposed that total emissions be decreased by one third of this amount (or 8,000,000 tons) by the year 1990. It is further proposed that nitrogen and sulfur emissions be considered on the basis of their equivalent contributions to acidity, that is, 2:1 for sulfur and nitrogen, respectively.

The following table shows an estimate of total tonage and relative percent of total emissions of sulfur dioxide in the subcontinent area for each relevant state and province in 1980. A similar table will be needed to estimate the relative contribution of each state and province to the total emissions of nitrogen oxides.

Concluding Remarks

This preliminary draft of a conceptual plan for management of acid precipitation has been developed in consultation with various scientists and both federal and state or provincial officials in both the United States and Canada. It is proposed for the purpose of stimulating further debate about the relevant scientific, political, economic, and social issues that relate to the quality of the air and water resources of this continent.

The scientists who drafted and the congressional leaders who have distributed this draft proposal, look forward to receiving critical review of the merits and limitations of this conceptual plan for management of acid precipitation and its effects on water quality and aquatic life.

Benefits derived from decreases in emissions of sulfur and nitrogen oxides aimed at avoiding harm in the aquatic environment will of course also have benefits in terms of:

1) effects on man-made materials and structures;
2) possible direct or indirect effects on human health;
3) effects on visibility in urban, rural and remote parts of the continent; and, perhaps most important of all,
4) possible effects on the long-term productivity of soils, forests, wetlands, rangelands, and agricultural crops, throughout North America.

United States and Canadian Emissions of Sulfur Dioxide in 1980 (Units = Tons Per Year x 1000)*

		Percentage of Total Emissions	
State or Province	Total Emissions	in USA	in USA and Canada
United States			
Alabama	604	2.9	2.5
Arkansas	100	0.5	0.4
Connecticut	118	0.6	0.5
Delaware	122	0.6	0.5
Florida	839	4.1	3.4
Georgia	580	2.8	2.4
Illinois	1,260	6.1	5.1
Indiana	1,968	9.5	8.0
Iowa	290	1.4	1.2
Kentucky	1,178	5.7	4.8
Louisiana	253	1.2	1.0
Maine	96	0.5	0.4
Maryland (including DC)	268	1.3	1.1
Massachusetts	335	1.6	1.4
Michigan	940	4.6	3.8
Minnesota	384	1.9	1.6
Mississippi	205	1.0	0.8
Missouri	1,286	6.2	5.2
New Hampshire	60	0.3	0.2
New Jersey	416	2.0	1.7
New York	860	4.2	3.5
North Carolina	448	2.2	1.8
Ohio	2,907	14.1	11.8
Pennsylvania	1,644	8.0	6.7
Rhode Island	26	0.1	0.1
South Carolina	260	1.3	1.1
Tennessee	1,034	5.0	4.2
Vermont	13	0.1	0.1
Virginia	386	1.9	1.6
West Virginia	1,145	5.6	4.7
Wisconsin	604	2.9	2.5
Subtotal	20,629	100	84
Canada			
New Foundland	72	1.8	0.3
Nova Scotia	217	5.5	0.9
New Brunswick	224	5.6	0.9
Quebec	1,105	27.8	4.5
Ontario	1,843	46.4	7.5
Manitoba	515	13.0	2.1
Subtotal	3,976	100	16
Total for all listed states and provinces	24,605		

* Adapted from Canadian-United States Working Group Report No. 2 Memorandum on Transboundary Air Pollution. July 1981.

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STATEMENT OF
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CORVALLIS, OREGON
U.S. ENVIRONMENTAL PROTECTION AGENCY
BEFORE THE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

MAY 27, 1982

Good morning Mr. Chairman and Members of the Committee. I am Dr. Robert T. Lackey, Senior Ecologist at EPA's Environmental Research Laboratory in Corvallis, Oregon. I welcome the opportunity to meet with you today to discuss the issue of aquatic and natural terrestrial effects of acid deposition and the related research effort underway at EPA. First, I shall briefly discuss the history of our research program on aquatic and natural terrestrial effects of acid deposition and its current status as well as the outlook for the next three to five years. Second, I shall highlight our major aquatic and natural terrestrial effects research objectives. Third, and finally, I shall discuss examples indicative of our work in this area.

Introduction and History of EPA's Research on the Aquatic and Natural Terrestrial Effects of Acid Deposition

EPA has conducted research relating to the aquatic and natural terrestrial effects of acid deposition for a number of years. Our activities have stemmed from broader concern over the potential adverse impact of acid deposition on crops, forests and their supporting soils, fish and other aquatic life, and water quality, including drinking water. For many of the lakes and streams in the United States and Canada, water quality is intimately linked to the processes in forested watersheds.

The current program under the National Acid Precipitation Assessment Program began to take shape early in Fiscal Year 1979 when EPA transferred research funds from other areas within the Agency and began to direct programs transferred from the Department of Energy to consider acid deposition.

Recently the funding levels for EPA's aquatic and natural terrestrial effects research have increased substantially, reaching in the 1983 budget before Congress, a Presidential request totalling $2.9 million. The total Federal budget request for this area is $6.5 million for FY 1983.

While a great deal has been learned to date regarding these types of effects of acid deposition, much needs to be better understood before informed regulatory decisions can be made. Major uncertainties exist in areas related to the effects on growth and yield of forests as well as the rate of lake acidification and the numbers of lakes at risk to acidification.

It is toward these and other uncertainties that our current effort is aimed.

Highlights of Aquatic and Natural Terrestrial Effects Research

Over the next three to five years we expect to gain knowledge in these areas from a number of research efforts currently underway, including the following:

Aquatic Effects

- Quantify the extent of acidification and the sensitivity of lakes, streams, and groundwater in the United States through the assembly of a National Inventory and additional field studies.

- Identify and quantify the factors which control the tolerance, sensitivity and susceptibility of surface waters and groundwater to acidification through studies of snow melts and watersheds and through development and use of acidification models.

- Identify and quantify the effects of surface water acidification on biological processes and populations through studies on fish and fisheries and wetlands effects and wildlife.

- Assess potential effects of acid precipitation on drinking water quality through completion of a survey of present and historical drinking water quality in New York and New England.

- Develop mitigation strategies for restoring or protecting acidified lakes and streams and conduct liming studies of lakes, streams, and limestone filtration of drinking water.

Natural Terrestrial Ecosystems

- Provide an experimental and conceptual basis for quantifying present or potential changes in forest productivity associated with acid deposition through such studies as tree ring analysis of forest growth and analysis of forest dieback in the Northeast.

- Quantify the integrative and mechanistic role of terrestrial watersheds in modifying and transmitting acidity and toxic elements to aquatic systems through study of nutrient accumulation and depletion and aluminum biochemistry in forested watersheds.

- Futher understand the role of soil chemical and biological processes as they mediate between forests and aquatic systems through study of mineral weathering and the influence of tree harvesting, internal acidification and acid precipitation.

Examples of Research on the Aquatic and Natural Terrestrial Effects of Acid Deposition

I would now like to discuss two examples of our work in the area of aquatic and natural terrestrial effects of acid deposition.

A major objective of our effort is the quantification and determination of changes in the quality of surface and groundwater caused by acid precipitation. We are now conducting a quantitative national assessment of the extent and magnitude of the problem.

A program has been implemented first by a national inventory to bring together, on a state-by-state basis, relevant water quality data already in existence, and to apply these data in various ways to assess the problem. This program is led by my laboratory and includes a number of other Federal agencies and national laboratories.

The objectives of this program are to:

(1) Identify and map the extent and degree of acidification and sensitivity to acidification of lakes and streams in the United States.

(2) Determine trends in the acidification of surface waters.

(3) Provide a verified, quality-assured data base to:

    (a) Apply available methodologies to predict surface water acidification based on given deposition rates.

(b) Relate patterns of surface water sensitivity with spatial patterns of climatic, physical, and land-use factors.

A second objective of research carried out under our program is the identification and quantification of the factors which control the tolerance, sensitivity, and susceptibility of surface and groundwaters to acidification. Research directed toward this objective generally focuses on studies in which terrestrial and aquatic factors are considered in relation to each other, emphasizing observation of their interaction and prediction of environmental responses. The most profitable approach to understanding these controlling factors is to study a number of watersheds receiving different levels of deposition and to develop, using these studies, models to predict the future status of lakes, streams, and groundwaters.

A number of studies utilizing watershed-stream-lake interactions are planned for FY83. At our Duluth Environmental Research Laboratory work has been ongoing since 1979 on thirty lakes and five calibrated watersheds, where research has focused on the snow accumulation-melt-impact process. EPA, in conjunction with the U.S. Geological Survey, is expanding this type of study into the Northeastern United States. These studies will attempt to define patterns which indicate sources, direction of transport, and sites of deposition of anthropogenic materials; assess the magnitude of inputs of chemical substances in snow and their impact on water quality; and evaluate the usefulness of regional snow chemistry in monitoring the distribution of atmospherically transported materials.

These studies, and others undertaken to meet these two research objectives, should give us in three years a very accurate picture of the status of lakes and streams. In five years we expect to be able to predict the status of various types of waters into the future under different loading conditions.

Summary

Mr. Chairman, this concludes my statement outlining our research program relating to the aquatic and natural terrestrial effects of acid deposition. I would be happy to respond to your questions.

Joan P. Baker

Testimony Presented to the
Senate Committee on Environment
and Public Works
27 May 1982

It is my belief that acidic deposition has resulted in the acidification of a large number of susceptible surface waters in areas of the northern United States, eastern Canada, southern Scandinavia, and perhaps others regions of the world. As a result of this acidification, biological communities in impacted lakes and streams have been altered. The best evidence for these responses comes not from any one particular area or study - none of which by themselves may be 100% convincing or complete - but instead from the total mass of evidence being accumulated by American, Canadian, and Scandinavian researchers. Unfortunately, in 5 to 10 minutes I can not come close to summarizing even the key points of this research. My testimony will therefore focus on data from the Adirondack Region of New York State - the most severely impacted area in the U.S. to date and also the region where I have personnally conducted research. My research was conducted from 1976 to 1980 at Cornell University in association with Dr. Charles Driscoll and Dr. Carl Schofield.

In 1975, Dr. Schofield and the New York State Department of Environmental Conservation (DEC) surveyed high elevation lakes in the Adirondacks and found that 52% of these lakes had pH levels below 5.0. Of the lakes with pH levels below 5.0, 81% had no fish (Schofield, 1976). High elevation lakes represent a select grouping of lakes which tend to be smaller, more susceptible to acidic deposition, and perhaps more acidic naturally. Therefore, it can not be inferred that 50% of all Adirondack lakes have pH levels below 5.0.

Unfortunately, a random survey of all Adirondack lakes has not yet been completed. High elevation lakes do, however, represent a region remote from most human activities and, in general, a pristine environment.

Data collected in 1975 and in years since then have indicated an unexpectedly large number of acid lakes in the Adirondacks. The key question is - is this relatively large number of acid lakes a result of acidic deposition. Alternatively, many of these acid lakes may have always been acidic due to the presence of natural organic acids, or the acidic conditions may have resulted from human disturbances other than the long range transport of air pollutants.

To address the first point, ideally we need historical records of past pH levels in acidic lakes. For a small fraction of the lakes in the Adirondacks we have such data - pH levels measured by the DEC in the 1930's. Of the 215 high elevation Adirondack lakes sampled in 1975, 40 have pH data recorded from the 1930's. Within this subset, in 1975, 47% had pH levels below 5.0 and 52% had no fish. In the 1930's, only 7% had pH levels below 5.0, and 10% no fish (Schofield, 1976). Similar changes in pH levels have been documented for lakes in New England. For example, for 123 lakes in Maine, the 1937-1942 mean pH level was 6.85 but down to about 5.95 in 1974 (Davis et al., 1978).

All of these studies are subject to several drawbacks. The most important drawback is the potential for error in the analytical measurement of pH. Today, pH measurements are typically made with a pH meter and are quite accurate. However, until fairly recently pH measurements were usually made colorimetrically - to a water sample a small amount of buffer solution was added and the color of the mixture that resulted was compared to a standard color scale. Unfortunately, in soft waters the pH of the water sample may be altered by the addition of even small amounts of buffer, and the pH reading may be biased. To try and account for this difficulty, data comparisons by the DEC for 138 Adirondack lakes utilized colorimetric pH measurements for both the 1930's and 1970's (Pfeiffer and Festa, 1980). In addition, recent surveys of New England and Adirondack waters (Norton et al., 1981 and Schofield, 1981) have compared present-day colorimetric pH measurements with present-day measurements using a pH meter, and concluded that the differences between readings due to analytical error are too small to account for differences between readings in the 1930's vs. 1970's.

There are other approaches that can confirm the acidification of surface waters without relying on colorimetric pH measurements. In a few instances, pH measurements utilizing a pH meter are available for the 1950's and 1960's that can be compared with present-day pH readings. For example, for 16 lakes in Halifax County, Nova Scotia, in all cases the 1977 reading was less than the 1955 reading, with the decline ranging from 0.1 to 0.8 pH units (Gorham, 1957; Watt et al., 1979). In addition, acidification of surface waters may be reflected by changes in water quality parameters other than pH level. Alkalinity represents the ability of a water system to absorb and neutralize acids. Therefore, with inputs of acids, as with acidic deposition, alkalinity will decline. Records of alkalinity from 1924 to the present are available from the Utica City Water Board for Hinckley Reservoir on West Canada Creek draining an area in the southwestern Adirondacks. A long term trend of decreasing alkalinity is evident (Schofield, 1976).

Thus, numerous studies in the Adirondacks and elsewhere indicate long term trends of increasing acidity in susceptible lakes receiving acidic deposition. Together they form conclusive evidence of the ongoing acidification of surface waters. It is true that some of the acid lakes in the Adirondacks are acid primarily because of natural organic acids and may have always been acid. But this natural acid source can not account for the increasingly large number of acid lakes in the Adirondacks today. For example, Dr. Charles Driscoll and I studied in detail the water chemistry of Big Moose Lake in the Adirondacks. It is a very clear lake, low in organic content. Organic acids apparently contribute little to its acidity and yet Big Moose Lake in 1977-1978 had a pH level of 4.7 to 5.0.

The question of the role of human disturbances other than long-range transport of air pollutants (e.g., logging or reforestation of farm or grazing land) in the acidification of surface waters has not been directly addressed for Adirondack lakes. Note, however, that the most acidic lakes in the Adirondacks, i.e., the high elevation lakes, are also the most remote from logging and other human activities. Also, recall that other regions, such as northern Wisconsin and southwestern Ontario, have also been heavily logged, and yet acidification of susceptible surface waters has not occurred. These areas have also not received large inputs of acidic deposition. In Scandinavia, several researchers have completed studies of the relationship between land use changes and acidification of lakes and streams (Drablos et al., 1980; Seip, 1980). No consistent correlation was found.

Certainly, in some instances natural organic acids and/or land use changes may play a role in acidification of a specific lake or stream. However, they can not explain the widespread and consistent acidification of "sensitive" lakes and streams in the northeastern U.S., eastern Canada, and southern Scandinavia.

Increased acidity has an impact on biological communities in aquatic systems. My discussion will focus on fish since my research has focused on fish. There are 3 major approaches to examine the effects of acidification on fish: (1) correlation of present-day levels of acidity in lakes and streams with the present-day status of fish populations; (2) examination of historical records and changes in fish populations with time; and (3) experimental verification of the effects of acidity on fish survival and growth in the field and laboratory. My research has involved principally the last approach, but I will briefly present evidence from each category.

As previously mentioned, in the 1975 survey of high elevation lakes in the Adirondacks, 52% of the lakes had pH levels below 5.0. Of these, 81% had no fish. Of the lakes with pH levels above 5.0, only 1% had no fish (Schofield, 1976). Presence or absence of fish is clearly related to lake acidity. Similarly, in a 1980 survey of 36 Adirondack streams by the DEC, none of the 10 streams with pH levels below 5.5 during spring snowmelt had resident fish populations. All but one of the 26 streams with spring pH levels above 5.5 had fish present during the fall of 1979 (Calquhoun et al., 1981).

It is possible that some of these acidic lakes and streams never had fish populations. However, it is also definite that many lakes and streams that, according to historical records, previously sustained fish - either through natural reproduction or stocking - now will not sustain fish - either through natural reproduction or stocking. The New York State Department of Environmental Conservation estimates that at least 180 lakes that previously had brook trout populations are now devoid of brook trout (Pfeiffer and Festa, 1980).

Historical data on specific lakes can also be examined in detail. For example, I have worked on South Lake in Herkimer County in the Adirondacks. A fairly large and accessible lake, South Lake was extensively stocked with brook trout and/or lake trout at various times from the 1930's up until 1978. Netting surveys by the State indicated that in the 1950's and 1960's trout were common in the lake. In the 1970's, however, fishing quality declined. Extensive survey netting from 1973 to 1975 yielded few lake trout and brook trout; in 1976 and 1978, no trout at all were collected (Baker, 1980; Pfeiffer and Festa, 1980). In 1979, South Lake had a pH of 4.9 to 5.0. Records of fish population status in a number of other Adirondack lakes reveal similar trends (Pfeiffer and Festa, 1980).

More complete records of changes in fish populations are available for other regions. For example, for 22 rivers in Nova Scotia records of angling catch of atlantic salmon per year are almost complete from 1936 to the present. Of the 10 rivers with current pH levels below 5.0, 9 have had statistically significant declines in angling success from 1936 to 1980; one had no significant trend in catch with time. Of the 12 rivers with current pH levels above 5.0, one has had a significant decline , one a significant increase, and 10 no significant trends in catch per year (Watts, 1981).

When examining trends in populations of game fish (e.g., brook trout, lake trout, and atlantic salmon) with time, it is important to incorporate into the analysis the possible effects of stocking policy and fishing pressure on fish population status. These complications can be avoided in the assessment of the effects of acidification on fish by utilizing data on non-game species. One such species that I have worked with is the white sucker. It is not a sport nor commercial fish, nor can it be caught with a hook and line, and white suckers are neither stocked nor systematically eradicated by fisheries personnel. The status of white sucker populations in Adirondack lakes is also clearly correlated with lake acidity. In high elevation Adirondack lakes, actively reproducing populations of white suckers were absent from lakes with pH levels below 5.2 (Schofield, 1976). In South Lake, the same decline in abundance is evident for white sucker populations as for brook trout and lake trout. Although DEC records indicate that white suckers were once abundant in South Lake, today only a few, older individuals remain. Succssful reproduction apparently has not occurred in a number of years. Personal observations in 1977, 1978, and 1979 found no evidence of spawning. The pH of South Lake in 1979 was 4.9 to 5.0.

The final approach to examing the effects of acidification on fish is to confirm experimentally that acidic conditions can kill fish. In 1977 and 1978, Dr. Charles Driscoll and I sampled 3 Adirondack lakes and their tributaries over the course of a year. From this and other studies it has been established that elevated aluminum levels are associated with acidic conditions (Driscoll et al., 1980). In a series of laboratory studies from 1977 to 1979 with young brook trout and young white suckers (Baker and Schofield, 1982), pH and aluminum levels within the range of those measured in acidic lakes and streams were found to be acutely toxic to fish and also to reduce fish growth. In addition, young fish were exposed to acidic Adirondack lake and stream water in the laboratory, and survival and growth monitored. In each instance, survival and growth were clearly correlated with the pH and inorganic aluminum concentration (Baker, 1980; Driscoll et al., 1980). These laboratory data provide strong support for the hypothesis that the low pH levels and high aluminum concentrations resulting from acidification of surface waters are responsible for the observed declines in fish populations in impacted waters in the northeastern United States, eastern Canada, and southern Scandinavia.

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TESTIMONY FOR THE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS OF THE UNITED STATES SENATE BY DR. LANCE S. EVANS

EFFECTS OF ACIDITY IN PRECIPITATION ON TERRESTRIAL VEGETATION

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ABSTRACT. Over the last several decades rain in the Northeastern United States has become more acidic presumably as a result of anthropogenic inputs of SO_X and NO_X to the atmosphere and their conversion to H_2SO_4 and HNO_3. Present experimental results suggest that acidic precipitation would initially affect organisms on leaf surfaces and epidermal cells of leaves of higher plants. More internal cell layers would be affected with increasing duration or frequency of exposure. Differences in responses of plant foliage among plant species to acidic precipitation appear to be due to the degree of leaf wetting and differences in responses of leaf cells to low pH rain. Moreover, within the same plant, particular structures or cell types may be more sensitive than others. If the United States is to utilize coal reserves for electric power generation that might increase rainfall acidity in the future, an assessment of the impact that acidic rain might have on terrestrial vegetation is necessary. An experiment was performed to determine changes in seed yields of soybeans exposed to simulated acidic rain grown under standard agronomic practices during the summer of 1981. Seed yields of field-grown soybeans exposed twice weekly to simulated acidic rainfalls of pH 4.1, 3.3, and 2.7 were decreased 10.7, 16.8, and 22.9%, respectively, compared with plants exposed to simulated

rainfalls of pH 5.6. Plants were shielded from all ambient rainfalls by two large (29 x 9 m each) moveable covers and simulated rainfalls were applied in quantities equal to the average amount of rainfall that occurs at the site. A treatment-response function of seed yield (y) per plant versus simulated rainfall pH (x) was $y = 7.40 + 1.025 x$ and had a correlation coefficient of 0.997. Researchers must design additional experiments with adequate experimental controls to assess the impact that acidic rain, at the present pH levels of 3.0 to 4.0 or at anticipated worst-case levels, that could occur if the acidity of rain should increase. Only a holistic view of the impacts that acid precipitation may have on vegetation will enable optimal energy and environmental policy decisions to be made.

1. Brief Literature Review - Effects of Acid Precipitation on Terrestrial Vegetation

The full impact that acidic precipitation is having on terrestrial vegetation has yet to be determined. Research to date has shown that plant responses can very greatly depending on species, environment, and method of exposure. Due to this variability, it has been necessary to study impacts of acidic precipitation on a plant-by-plant basis. From this approach an overall picture of which plant groups are most sensitive and the types of injury which occur is beginning to emerge.

1.1. ACIDIC RAIN INDUCED LESIONS ON VEGETATION OCCUR MOSTLY ON LEAVES AND REPRODUCTIVE STRUCTURES

Simulated rain at pH 3.4 is about the highest pH at which visible lesions on leaves have been observed. Lesions are located preferentially at bases of trichomes, in guard cells, and in epidermal cells above veins (vascular tissues). A large percentage of the leaf area may exhibit lesions. [1-8].

1.2. PHOTOSYNTHESIS AND RESPIRATION IN FOLIAGE MAY BE INFLUENCED BY EXPOSURE TO ACIDIC PRECIPITATION

Leaves exposed to low pH simulated rain (pH 2.3) had lower sugar and stretch contents compared with plants exposed to simulated rain of pH 5.7 [4]. Foliage exposed to acidic rain may be stressed but short-term measurements of photosynthesis and respiration may not be sensitive enough to detect the degree of stress. The relationship between the changes in carbohydrate status, on long-term bases, with loss of plant and seed biomass must be more firmly established.

1.3. ACIDIC PRECIPITATION INFLUENCES NUTRIENT LEACHING FROM PLANT SURFACES

Acidic rain can cause an increased rate of foliar leaching. Wood and Bormann [9] demonstrated that K^+, Ca^{2+}, and Mg^{2+} were leached from leaves of pinto beans more rapidly at pH levels of 3.0 and 3.3 than at pH levels of 4.0 and 5.0. Ca^{3+} leached faster from foliage of sugar maple than K^+ or Mg^{2+} at pH 3.0 than at pH 3.3. Leaching rates of K^+ and Mg^{2+} were similar at all pH levels between 3.0 and 3.3. However, the leaching rate at pH 3.0 was significantly higher than at pH 4.0 for K^+ and Mg^{2+}. In tobacco leaves, Ca^{2+} leached faster from foliage exposed to simulated rain of pH 3.0 than foliage exposed at pH 6.7. [10] In pinto beans exposed to simulated rain for 5 days, more Ca, nitrate, and sulfate were leached from foliage at pH levels of 2.7 and 2.9 than at a control pH of 5.7 [11] In contrast, the amount of K leached was greater from leaves exposed to pH 5.7 than leaves exposed to 2.7 or 2.9. The amounts of ammonium, Mg, and Zn leached were the same at all pH levels tested.

In addition to removal of plant nutrients from foliage, nutrients may also be removed from tree bark and crows via stem slow. [12] Measurements of electrolytic conductivity of bark extracts of forest trees were more sensitive than measurements of pH or sulfate to inputs of sulfate and/or acid rain. [13]

Bark surfaces may be better indicators of nutrient accumulations than wood samples taken from trees. [14] Although seasonal variations in buffering capacity were present, bark extracts taken from Cracow City were more acidic than bark extracts taken from locations more remote from industrial areas. Tree barks that are naturally less acidic have a rough texture, such as linden and ash, are most suitable to detect pollutant accumulations. [14]

Since the relationship(s) between the exchange of cations and anions and the physiological state of cellular metabolism remains unclear, only continued efforts in this area will demonstrate the impact(s) of acidic precipitation on nutrient leaching and plant growth.

1.4 ACIDIC PRECIPITATION MAY AFFECT GAS EXCHANGE IN PLANTS

Individual epidermal cells are injured upon initial exposure to acidic rain [6, 7] Moreover, acid rain may cause alterations in the cuticle and/or functions of guard cells [15] Foliage exposed to acidic rain may be more subject to wilting or water stress as well as becoming more sensitive to gaseous air pollutants. Knowledge of the effects of acidic rain in combination with gaseous pollutants such as O_3 and SO_2 is needed in order to understand the total impacts acidic rain might have on vegetation in nature.

1.5. ACIDIC PRECIPITATION CAN AFFECT TOTAL PLANT PRODUCTIVITY

Significant reductions (19% and 11%) in dry weight of trifoliate leaves and dry weights of pods and seeds, respectively, of pinto beans occurred after exposure to acidic mists with no visible injury. [5] Wood and Bormann [3] showed that simulated acid mists of pH 3.0 did not reduce plant growth rates of yellow birch even though all leaves exhibited leaf pitting and curling. However, with many crop plants, yield may be determined by development and survival of reproductive organs as well as by cumulative injury to foliage.

Simulated acidic rain of pH 3.1 and below decreased the dry mass of seeds, leaves, and stems of pinto beans grown under greenhouse conditions. [15] On a percentage-mass basis the decrease in seed yield was comparable with reductions in biomass of leaves and stems. The decrease in yield of pinto beans by simulated acidic rain was attributed to both (1) a decrease in number of pods per plant and (2) a decrease in number of seeds per pod. In soybeans, simulated acidic rain decreased dry mass of both stems and leaves. Seed yield also decreased after treatment with rain of pH 2.5. However, an increase in seed yield occurred when plants were exposed to rain of pH 3.1. A larger dry mass per seed was responsible for the larger dry mass of seed per plant. Lee et al. [17] showed that marketable yield was reduced for 5 crops (radish, beet, carrot, mustard greens, and broccoli) and stimulated for 6 crops (tomato, green pepper, strawberry, alfalfa, orchard grass, and timothy) when they were treated with acidified rain in field chamber tests. No consistent effects were observed for 16 other groups.

In a field experiment at Brookhaven National Laboratory, radishes and garden beets were exposed to simulated acidic rain. Yields of radish were not affected by acidic rain treatments. Beet plants treated with simulated rain applications of pH 4.0, 3.1, and 2.7 showed significant decreases in yield compared with yields of both the ambient rainfall only and pH 5.7 simulated rain treatments. Root yields of beet exposed to simulated rain at pH 5.7, 4.0, 3.1, and 2.7 were 110, 79, 84 and 86% of those receiving ambient rainfall only. Foliar injury on beet was attributed to exposure both to simulated acidic rain of pH 4.0, 3.1, and 2.7 and to several consecutive ambient rainfalls which had an average pH of 3.9. This is the first experiment showing visible foliar injury due to either ambient rainfalls or simulated rain above pH 3.1 under agronomic conditions.

1.6. ACIDIC PRECIPITATION AFFECTS UNICELLULAR ORGANISMS

Most multicellular organisms that have evolved from aqueous environments onto dry land have evolved specialized surfaces to retard desiccation. Organisms with protective coverings may be less sensitive to acidic rain than organisms that lack these coverings. Bacteria and other single-celled organisms are very sensitive to pH changes. Procaryotic organisms seem to survive within a smaller range of pH levels than most multicellular organisms. Motility of most procaryotic organisms is greatest between pH 6.8 and 9.0. [19-21] Heoninger [22] showed that a pH decrease results in an increase in abnormal wave motions in flagella of Proteus. Below pH 5.0 almost all motility ceased.

Fertilization and spermatozoid motility in fern gametophytes is very sensitive to low pH and additions of sulfate, nitrate, and chloride.[23-25] Acidity inhibited one or more critical stages during reproduction. Fern fertilization is inhibited by pH levels below 5.7 and additions of sulfate and nitrate (43 μm). These results suggest that the acidity of ambient precipitation in the northeastern United States inhibits reproduction of ferns [25].

1.7. ACIDIC PRECIPITATION CAN AFFECT MICROORGANISMS THAT INHABIT SURFACES OF HIGHER PLANTS

Simulated acidic rain produced an 86% inhibition of the number of telia of Cronartium fusiforme on willow oak (Quercus phellos) and a 29% decrease in the percentage leaf area affected by bean rust(Uromyces phaseoli) on Phaseolus vulgaris. [26] Halo blight caused by Pseudomonas phaseolicola infections of leaves of Phaseolus vulgaris was stimulated and inhibited by simulated acidic rain depending upon the timing of application. Simulated acidic rain inhibited initial infection but stimulated pathogen development if applied after infection began.

1.8. EFFECTS ON FOREST PRODUCTIVITY

There have been conflicting reports as to whether acidic precipitation can influence forest productivity. Tamm [27] concluded that except in areas where forest trees exhibit visible pollution symptoms, ambient acidic precipitation or other types of atmospheric acidity have no effect on tree growth. Other researchers found a statistically significant difference in tree growth between areas exposed to acidity and areas more remote from transported atmospheric acidity. [2, 28] They concluded that there was no reason to attribute growth reduction to anything other than acidic rain. Researchers in Norway [29] and the United States [30] have not detected any consistent decrease in tree growth which could be attributed to acid deposition.

2. Soybean Field Experiment at Brookhaven National Laboratory

An important area of interest is to determine the effects of acidic precipitation on yields of agronomic crops under field conditions since foliage of broad-leaved angiosperms appear most sensitive to simulated acidic rainfalls. [8] Experiments of this nature must have large sample sizes, adequate randomization of treatment plots to avoid local soil problems, and appropriate statistical analyses. Experiments described herein were performed with field-grown soybeans at Brookhaven National Laboratory during the summer of 1981. Preliminary experiments were performed to estimate the most appropriate plot design and statistical analyses. Changes in soybean yields could have significant economic implications (total value of all soybeans grown in the United States in 1979 was $14 billion. [31]

Soybean seeds (Glycine max cv. Amsoy 71) were inoculated with Rhizobium japonicum. After plowing to a depth of 23 cm, the field was harrowed and fertilized (3.36 quintals per ha of limestone and 4.5 quintals per ha, 5-10-10-3, N-P-K-S). The fertilizer recommendations [32] were based on soil analyses.

Soybean plants were spaced 6.6 cm apart within a row and rows were spaced 38 cm apart to provide 380,000 plants per ha. Each plot consisted of 4 rows, 1.52 m in length (Table 1). Plots were arranged into 8 Latin Squares, within each of which treatments were repeated 4 times. Ambient rainfalls were excluded from the experimental field area through the use of two moveable covers, each measuring 29.3 x 9.1 m, which were manually positioned over the field before and were removed after each ambient rainfall. The nozzle arrays used to apply the simulated rainfalls were attached to the framework of the covers. Therefore the covers were also placed over the plants during treatment applications. In order to avoid exposure of plants to elevated temperatures which might occur under the covers during the daytime, simulated rainfalls were applied only during the late afternoon and evening. Plants were exposed to simulated rainfalls of either pH 5.6, 4.1, 3.3, or 2.7. Rainfalls of pH 5.6 represented "non-acid" rain. pH 4.1 represents the weighted mean of the hydrogen ion concentration of rainfalls at Brookhaven National Laboratory for the summers of both 1979 and 1980. Rainfalls of pH 3.3 and 2.7 were used to assist in determining a dose-response function. The lowest pH observed in ambient rain at this site is 3.0 and rainfalls between pH 3.0 and 3.5 amounted to 7% of all events during the growing season of 1980 [33, 34]. A simulated rain solution based on the average composition of rain in the New York and New Jersey area was used. The ionic strength of the simulated rain treatments was similar to natural rain of comparable pH levels [11]. Plants were exposed twice weekly for 1.75 hr per exposure. A rainfall equivalent of 1.27 cm per exposure (2.54 cm week^{-1}) was applied. The mean amount of rain per week during the growing season (May through September) at Brookhaven National Laboratory is 2.1 cm [35]

Soybean seed yields decreased 10.7, 16.8, and 22.9% with treatment pH's of 4.1, 3.3, and 2.7, respectively, compared with plants exposed to simulated rainfalls of pH 5.6 (Table 2; Fig. 1). The observed decrease in seed mass per plant with decreasing treatment pH resulted from a decrease in number of mature pods per plant. Reduced numbers of mature pods were also observed in a previous field test [33]. The number of seeds per plant also decreased since the number of seeds per pod and the mass of individual seeds did not vary among the treatments.

A treatment-response function was determined for the relationship between the pH of the simulated rainfall and seed yield (Fig. 1). This function is described by the equation $\hat{y} = 7.40 + 1.025\ x$, where y is seed mass per plant and x is the pH of the simulated rain. This equation describes a line which has a correlation coefficient of 0.997 and a slope that is significantly different from zero ($p = 0.0018$).

When such dose-response functions are made, some consideration to sources of variability and uncertainty must be made. The levels of uncertainty due to differences in cultivar, variations in edaphic and climatic factors are probably intermediate to high. Few reliable studies are available to evaluate these influences. Studies at Brookhaven National Laboratory may help to estimate how variations in yield per plant occurred among three growing seasons, probably due, in part, to edaphic and climatic conditions, the impacts of simulated acidic rainfalls on soybean yields were markedly similar during the years of 1978, 1979, and 1981 [33, unpublished results]. These results suggest that the variability of impacts to soybean yields among various years is probably low.

Such a reduction would affect yields independently of other sources of variation (except drought). Yield reductions due to acidic precipitation of the magnitude observed in this experiment may go undetected in commercial production because other, more easily observed agronomic and climatological factors can cause annual variations in yield which are of equal or greater magnitude. This variation is exhibited by the wide range of mean annual yields (1714.2 to 2131.0 kg ha^{-1}) which occurred from 1970-1979 [37].

3. Summary

At the present time several studies have demonstrated crop yield reductions. However, economic losses due to ambient levels of acidic precipitation cannot be established with available data. More scientific research is necessary to evaluate the impacts of acidic precipitation on terrestrial vegetation (both crops and natural ecosystems).

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Table 1. Experimental Design

Duration of the experiment	18 weeks (30 May - 27 September 1981)
Duration of experimental treatments	15 weeks (2 June - 11 September)
Duration of each rainfall	1.75 hour
Total deposition per simulated rainfall	12.7 mm
Number of simulated rainfalls	30
Frequency of simulated rainfalls	2 per week
Total deposition of all simulated rainfalls	381 mm
Number of plots per treatment	32
Individual plot area	2.3 m^2
Number of harvested plants per plot	26

	Sulfate		Nitrate	
Treatments	Concentration (mg l^{-1})	Total Deposition (g m^{-2})	Concentration (mg l^{-1})	Total Deposition (g m^{-2})
Simulated rain of pH 5.6	0.85	0.32	0.66	0.25
" " " " 4.1	3.9	1.49	1.5	0.57
" " " " 3.3	21	8.00	5.8	2.21
" " " " 2.7	81	30.86	21	8.00

Table 2. Seed yield characteristics of field-grown soybeans exposed to simulated acidic rain.

Treatment	Seed mass per plant (g)	Pod number per plant	Seed number per plant	Seed number per pod	Mass per seed (g)	Seed yield (quintals ha^{-1})	Plant populatio (number ha^{-1})
Rain pH of 5.6	13.1^a	27.3^a	69.6^a	2.6^a	0.19^a	46.6^a	$358,577^a$
" " " 4.1	11.7^b	23.5^b	60.5^b	2.6^a	0.19^a	41.7^b	$358,691^a$
" " " 3.3	$10.9^{b,c}$	23.3^b	$58.5^{b,c}$	2.5^a	0.19^a	$39.0^{b,c}$	$361,293^a$
" " " 2.7	10.1^c	21.0^c	52.3^c	2.5^a	0.19^a	36.7^c	$367,087^a$

Mean values followed by a different letter are significantly different ($p < 0.05$) by analysis of variance [36]. Values followed by the same letter are not significantly different. The pooled standard error of seed mass per plant is 0.32.

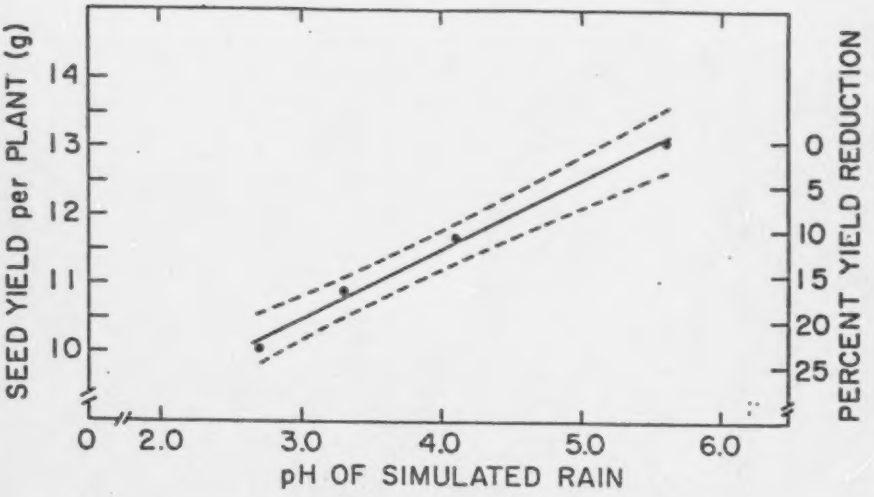

Fig. 1. Relationship between soybean seed yield per plant and the hydrogen ion concentration of the treatments. Statistical analyses of this relationship are shown in Table 2. Confidence (95%) lines (dashed lines) are drawn above and below the best fit line.

Status of Research on Acid Deposition and Forest Growth

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Forest ecosystems are complex and dynamic assemblages of organisms, water, minerals and gases. Accordingly, many aspects of forests have been studied in acid deposition-related research. This summary focuses on the effects of acid deposition on the growth and health of forest trees. The research can be split into two general types--experimental and empirical. The experimental research has involved subjecting plants to varying levels of acid intensity and measuring the responses. From those types of studies we have learned what acid deposition can do. The empirical research has been conducted largely by coring trees to determine patterns of growth rate from the annual rings then trying to determine if historical or regional trends in acid deposition are related to the observed growth patterns. From the empirical research we have obtained a "signal" which indicates that in some species in some regions, growth rates have been lower than expected since the early or mid-1950's. The nature of the empirical research and the complex array of environmental factors to which tree growth responds precludes confident assessment of whether or not acid deposition is a factor contributing to reduced growth. Our understanding will improve as experimental work is done with species and ecosystems where empirical studies have indicated a change in growth rate.

Theoretical considerations suggest that acid inputs (H^+) are more likely to be bad than good, that the effect of sulfate might be good or bad depending on the behavior and amount of sulfur in the soil, and that the effect of nitrate is more likely to be good rather than bad. There is evidence from experimental work that acid deposition can have direct or indirect effects on vegetation, and that the effects can be positive (stimulatory) or negative. We can identify the following effects which occurred with acid doses similar to the most acid ambient precipitation:

increased nutrient loss from foliage
erosion of cuticular waxes from leaves and needles
decreased seed germination/seedling growth
increased seed germination/seedling growth
premature senescence of foliage
foliar lesions
increased cation (nutrient) leaching from soils
increased aluminum solubility (aluminum is toxic to many plants)
enhanced ozone stress
decreased activity of soil bacteria which decompose organic residues
decreased nitrification by autotrophic bacteria

It is difficult to extrapolate any of the experimental results to predict what acid deposition is actually doing in forests because the experimental conditions were simplified relative to those in natural forests, and the duration of the experiments was short relative to the growth and development of a tree.

The most comprehensive studies of acid application to forests have been done in Norway over the past decade. In those studies, growth was stimulated in some species, reduced in others, but the changes were so slight that the effects are not considered to be significant.

The sum of the experimental work carried out to date indicates that acid deposition at levels now experienced can have effects that might caused reduced growth in forests. There are also results which indicate that acid deposition can stimulate growth, at least in the short run.

Several empirical studies of tree growth and health have been carried out in the last decade in North America and Europe. Results of a decade-long study of Norway spruce in Germany suggest that acid loading by ambient precipitation has increased soil aluminum mobility, increased aluminum uptake by roots to toxic levels, caused root dieback and subsequent death to susceptible individuals. The circumstantial evidence for this chain of acid deposition-induced events is sound, but experimental confirmation is lacking.

Several investigators have used historical patterns of tree rings, data on climate and other environmental parameters, and regional or historical patterns of acid deposition to determine if acid deposition could be affecting tree growth. Several studies have been done in North America, Sweden and Norway which indicate that growth rates have been less than expected for the past 20 to 30 years. The methods by which the investigators sought to determine if acid deposition was an important factor varied, but the sum of the evidence leaves acid deposition as a possible cause. No cases of growth rate increases in natural, unmanaged forests have been reported which are coincident with spatial or temporal patterns of acid deposition.

The findings of research in which I am personally involved can be summarized as follows:

> Widespread, substantial and sustained decreases in growth rate which began during the last two or three decades have been observed in pitch pine and shortleaf pine in southern New Jersey.
>
> Substantial records of historical stream pH indicate that the streams in the region became increasingly acid between 1960 and 1980. Correlations among stream pH, precipitation pH, climatic data, air quality data, and tree growth suggest that acid deposition is a stress related to the growth rate decline.
>
> Red spruce rings in Vermont and New Hampshire show a reduction in growth during the past 20 years similar to that observed in New Jersey pines. Furthermore, a dieback of red spruce in Northern Vermont has been quantitatively documented. Substantial spruce mortality is visible in New Hampshire, New York and Connecticut.
>
> Work to date on pathogens, climate, fog and rain chemistry, foliar chemistry, root chemistry, patterns of tree rings, and air quality indicate that acid deposition is a plausible contributing or controlling stress in the spruce dieback phenomenon. At present, there are few clues which point to another mechanism.

Thus changes in tree growth have been identified. The cause is unknown. The reduction in growth and the mortality cannot be attributed to climatic changes or any other obvious factors. Acid deposition is a plausible cause or contributing stress, and has been implicated in some cases by circumstantial evidence.

Given that we cannot determine what acid rain is actually doing to tree growth at present, we have little basis for predicting what may happen in the future. One key consideration is the effect that acid deposition will have on the loss of nutrients from forest soils. There is little doubt that acid deposition _can_ accelerate the loss of some nutrients from soils. How much affect this may ultimately have on tree growth depends in part on a combination of other factors which affect nutrient capital. The types of soils which might be most susceptible to nutrient loss have been identified, but the timing and magnitude of effects due to acid deposition-induced nutrient depletion cannot be adequately predicted.

Another important consideration in predicting future effects is to define the effect of acid deposition on seedling establishment and growth in the current forests, since the forests of the future will be comprised of trees which reproduce and compete effectively. Acid rain _can_ affect seedling establishment and growth as shown in experimental research, but we do not have sufficient evidence to even speculate about whether or not forest composition may change as a result of acid deposition.

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Sponsored Research

1976-77	Reclamation of industrial wastes, Nicolet Inc. (Principal Investigator)
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EFFECTS OF ACID RAIN ON FOREST NUTRIENT STATUS

Acid rain has created a major concern because of the potential for accelerated cation leaching from forest soils and eventual losses of forest productivity. This concern was the driving force for numerous studies of acid rain effects on forest nutrient status in general and cation leaching in particular.

Perhaps because of the negative implications of the term "acid rain", initial speculations about acid rain effects on forest productivity devoted little or no attention to concurrent sulfate (S) and nitrate (N) deposition on forests deficient in S or N. Only recently has it been recognized that acid rain can cause increases as well as decreases in forest productivity because of associated S and N deposition.

It is also very important to recognize that acid is generated naturally by the plant community (Ulrich, 1980). Thus, the question is one of relating atmospheric inputs to natural levels, e.g., does atmospheric acid input significantly add to natural acid production within the soil? Do the detrimental effects of acid deposition offset the benefits of concurrent S or N?

Deficiencies of S have been indicated in forests remote from pollutant inputs in the Northwestern U.S. Australian research suggests strongly that pollutant inputs from power plants are beneficial in S-deficient forests.

It has been clearly shown that fertilization with N, a common practice in many forested regions of the U.S., results in the rapid utilization of ecosystem S supplies, possibly leading to S limitations. In relatively unpolluted regions of the northwestern U.S., there is evidence that lack of Douglas-fir growth response to N is due to marginal S status. Thus, it seems evident that moderate amounts of acid rain as H_2SO_4 could especially benefit forests undergoing fertilization with N. In the U.S. this currently involves a total of about 1,000,000 ha of forest lands, primarily in the Northwest and Southeast.

Amounts of atmospheric S input sufficient to satisfy forest S requirements are fairly modest however. Inputs of SO_4-S in the eastern U.S. frequently exceed forest S requirements by a factor of 2-4. Excess S cycles within vegetation and accumulates in soils as SO_4^{2-} without any apparent harm however. Indeed, adsorption of SO_4^{2-} in soils can prevent leaching of cations by atmospheric H_2SO_4 inputs.

Deficiencies of N are very common in forests throughout the world and inputs of NO_3^- (as well as forms of N) are very likely to improve forest nutrient status and productivity in most cases.

Since forest N requirements are relatively high compared to S, there are very few instances of atmospheric NO_3^- inputs associated with acid rain in excess of forest N requirement. There is little doubt that acid rain can accelerate cation leaching rates, but the magnitudes of these increases must be evaluated within the context of natural, internal leaching processes.

The importance of accelerated cation leaching to forest nutrient status depends very much on the magnitude of the cation reserves within the soil. If the reserves are very large relative to leaching rates (such as in calcareous soils), a doubling or tripling of leaching rates due to acid rain are probably of little consequence. If reserves are small (such as in highly weathered soils), doubling or tripling of leaching rates may have long-term significance. Cases in which soil reserves can be significantly depleted by acid rain may occur in some cation-deficient sandy soils of the Northeastern U.S. However, rates of mineral weathering to replenish cation nutrient supplies in such cases are unknown as yet.

Recent work by Prof. Ulrich has suggested that acid rain, in concert with internal acidification processes, is causing mobilization of Al^{3+} to toxic levels in forests of West Germany. This hypothesis has been suggested as a cause of red spruce decline in the northeastern U.S., but recent work by Art Johnson fails to support it. Furthermore, another noted German forest soil scientist disputes this claim to some extent, arguing that while acid rain in sufficient amounts could theoretically produce such effects, there is no reason to suspect widespread toxicity in German forests.

The degree of Al mobilization from soils and the effects of Al on trees will vary with site and species. Artificial irrigation studies have shown that Norway spruce, one of the species thought by Dr. Ulrich to be endangered in Germany, can tolerate very high levels of Al under both field and laboratory conditions in Norway. Furthermore, tree species are known to vary enormously in their sensitivity to Al. Thus, generalizations about acid rain and Al effects on forests are hazardous.

Summary and Assessment

It is clear that acid rain in the form of H_2SO_4 and HNO_3 will increase the supplies of S and N (respectively) and decrease the supplies of cations (by leaching) in forest ecosystems. The only questions are, by how much and of what consequence are such increases or decreases to the overall nutrient status of the forest in question. Since nitrogen limitations are so common and cation nutrient limitations are so rare in forests of the U.S., it seems likely that HNO_3 inputs will generally be beneficial. Exceptions will certainly occur on sites with adequate or excessive N supplies. Benefits of H_2SO_4 deposition are probably minimal since S deficiencies are rare and probably easily satisfied with moderate atmospheric S inputs (i.e., 5 kg $ha^{-1}.yr^{-1}$ in most cases).

In terms of long-term effects (i.e., many decades to centuries), acid rain can be expected to deplete *total* cation supplies in forests, but it is not at all clear whether such depletions will cause reduced available cation supplies and acidification of soils. That is, 1) cation leaching rates, though increased by acid rain, may well remain at insignificant levels relative to total soil supplies and forest growth requirements; and 2) soil available cation supplies may be replaced by weathering from primary soil minerals at rates currently unknown and perhaps stimulated by acid rain inputs themselves.

In any event, the problem of assessing acid rain effects on forest nutrient status is entirely one of quantification of the amounts of inputs involved and the S, N, and cation nutrient status of the specific forest sites in question. By no means can it be stated that forest ecosystems, in general, will respond to acid rain in any single way.

The following quote by the 16th century physician Paracelsus while addressed to the issue of human toxicology, is entirely appropriate to the question of acid rain and forest nutrient status:

> "All substances are poisons; there is none which is not a poison; the right dosage differentiates a poison from a remedy" (Paracelsus, 1493-1541).

STATEMENT BY
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My name is Orie L. Loucks, Science Director of The Institute of Ecology, Indianapolis, Indiana, and for 16 years previously Professor of Botany, Forestry and Environmental Studies at the University of Wisconsin. I have worked in Plant Science for some 30 years, and on the effects of environmental toxicants on natural resources for much of the past 15 years. As Science Director for The Institute of Ecology, a national consortium of universities, I lead a number of inter-institutional studies of environmental problems including work on acid rain and related air pollution effects.

We are all aware your Committee has already taken much public testimony on amendments to the Clean Air Act. Accordingly, I will limit my observations, first to selected new results, and secondly to very recent analyses of federal actions that would be responsive to the public need.

A. How Many Lakes and Streams Have Been Affected by Acidic Deposition

To develop an inventory of sensitive (but not necessarily altered) lakes and streams in the eastern United States, we adopted a procedure developed by Oak Ridge National Laboratory using data on soil, watershed, and bedrock characteristics in 27 eastern states to generate a list of individual counties whose freshwater resources were potentially sensitive to acidic deposition. The counties are summarized in Table 1, and are aggregated into 14 acid-sensitive regions (Figure 1). Using U.S. Geological Survey Maps, we systematically sampled each region to estimate the total number of lakes greater than 15 acres in size, and total miles of first- and second-order streams. The results show an estimated 17,000 lakes and 117,000 miles of first- and second-order streams in the fourteen sensitive regions (Table 2).

Table 1. State areas (in square miles), shown along with number and area of counties in each state identified as meeting aquatic resource sensitivity criteria (see Table 3), and the proportion of the states meeting these criteria.

	State	Total area (mi^2)	Number sensitive counties	Sensitive area (mi^2)	% of total state area
States with some sensitive areas					
1.	Alabama	51,609*	4	4,184*	8
2.	Connecticut	5,009	all(8)	5,009	100
3.	Georgia	58,876	10	4,393	8
4.	Indiana	36,291	11	4,339	12
5.	Kentucky	40,395	29	10,692	27
6.	Maine	33,215	all (16)	33,215	100
7.	Maryland	10,577	2	1,338	13
8.	Massachusetts	8,257	11	6,796	82
9.	Michigan	58,216	3	3,290	6
10.	Minnesota	84,068	19	29,430	35
11.	Mississippi	47,716	25	14,317	30
12.	New Hampshire	9,304	all (10)	9,304	100
13.	New Jersey	7,836	12	4,173	53
14.	New York	49,576	39	33,938	69
15.	North Carolina	52,586	20	8,748	17
16.	Pennsylvania	45,333	26	17,719	39
17.	Rhode Island	1,214	all (5)	1,214	100
18.	South Carolina	31,055	2	1,172	4
19.	Tennessee	42,244	1	468	1
20.	Vermont	9,609	6	4,760	50
21.	Virginia	40,817	25	10,860	27
22.	West Virginia	24,181	13	7,585	31
23.	Wisconsin	56,154	31.5	28,080	50
States with no identified sensitive areas					
1.	Delaware	2,057	0	0	0
2.	Florida	58,560	0	0	0
3.	Illinois	56,400	0	0	0
4.	Ohio	41,222	0	0	0
TOTAL AREA		962,377	328.5	245,024	25

* Areas of states and counties taken from Computer Graphics, Geography Division, Office of Technology Assessment.

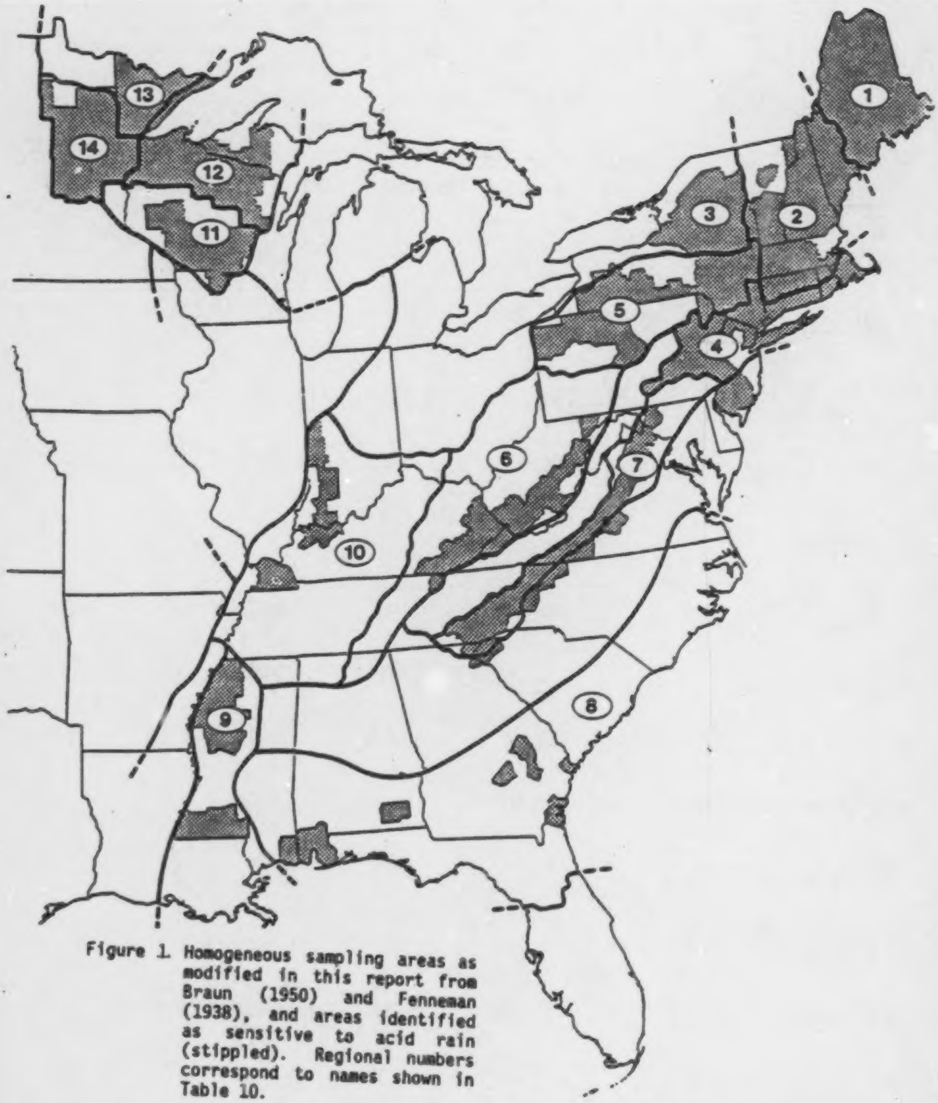

Figure 1. Homogeneous sampling areas as modified in this report from Braun (1950) and Fenneman (1938), and areas identified as sensitive to acid rain (stippled). Regional numbers correspond to names shown in Table 10.

Table 2. Total lake and stream resources estimated for the acid sensitive regions of the Eastern U.S. (see Figure 9). Lake estimates have a reproducibility of 10 to 20%, and stream estimates approximately 10%.

Region	Sensitive Area (mi^2)	- -Total Lakes- - Number	Acres	-Total Streams (mi)- 1st Order	2nd Order
1. Eastern Maine	26,398	1,425	582,825	9,714	3,485
2. Western New England	29,666	1,543	763,785	15,308	4,569
3. Adirondacks	14,066	1,139	231,217	5,289	3,024
4. East Pennsylvania S. New England	20,947	1,320	118,800	8,400	2,556
5. W.New York/Pennsylvania	25,051	376	16,920	7,114	1,678
6. Appalachian Plateau	16,190	13	29,510	7,350	2,299
7. Blue Ridge/ Great Smoky Mts.	20,964	126	14,868	10,901	3,396
8. Coastal Plain	9,264	241	8,917	1,547	713
9. Lower Mississippi	13,075	170	56,610	5,374	1,255
10. Indiana/Kentucky	8,603	9	603	2,805	989
11. Central Wisconsin	12,141	583	187,726	2,683	728
12. Wisconsin/Michigan Highlands	19,229	5,307	801,357	5,037	1,737
13. Northeast Minnesota	10,560	1,637	473,093	1,637	475
14. Central Minnesota	18,870	3,170	323,340	4,831	2,529
TOTALS	245,024	17,059	3,609,571	87,990	29,433

Of this total number of lakes and streams in the sensitive regions, only a portion may be considered sensitive to acid inputs. Under unaltered conditions, virtually all lakes and streams have some acid-neutralizing capacities. Like soils, their waters contain chemical substances such as bicarbonate, which neutralize the entering acids. Alkalinity levels, which are expressed in microequivalents per liter of water (µeq/ℓ), measure the acid-neutralizing capacity of lakes and streams. Lakes and streams defined as very sensitive to acidic inputs have alkalinity levels of 0-40 µeq/ℓ, while a lake with high capacity for acid neutralization can measure over 500 µeq/ℓ. Alkalinity levels in lakes and streams also depend on geochemical conditions in the surrounding watershed and underlying bedrock. If the surrounding watershed contains little neutralizing material, natural alkalinity levels in lakes and streams may be quite low, making these aquatic resources highly sensitive to even low levels of acidic inputs. Thus, local variations in geology, soil conditions, and runoff patterns cause alkalinity levels of lakes and streams within a sensitive region to range from less than zero µeq/ℓ (acidified), to over 500 µeq/ℓ (acid resistant).

Data from regional water quality surveys then were used to estimate the percentage of the lakes and streams in the 14 regions that can be considered sensitive to acid deposition, using a 200 µeq/ℓ alkalinity level as the cut-off point between sensitive and non-sensitive lakes and streams. Results show an estimated 9,400 lakes and 51,000 miles of streams that are either currently sensitive to or have previously been altered by acid inputs (Tables 3 and 4).

To estimate the portion of these sensitive lakes and streams that have already been altered by acidic deposition, we compared data on the distribution of alkalinity levels for two distinct geographic areas: a) regions with little neutralizing capacity that currently receive high (resource-affecting) levels of acidic deposition, and b) geologically similar areas of northwestern Ontario and northern Minnesota having little neutralizing capacity, but that receive negligible amounts of acid deposition. The difference between the two distributions estimates the proportion of lakes and streams that can be considered "acid-altered," rather than simply sensitive. Calculations using this approach show an estimated

Table 3. Total lake resources present and at risk in the acid sensitive regions of the Eastern United States.

Region	Sensitive Area (mi^2)	Total Number Lakes (±10%)	Percentage of Lakes <200 ueq/ℓ (± 10-20%)	Calculated No. Lakes at Risk (±20%)
1. Eastern Maine	26,398	1,425	(80)[1]	1,140
2. Western New England	29,666	1,543	(80)[1]	1,234
3. Adirondacks	14,066	1,139	80	911
4. East Pennsylvania S. New England	20,947	1,320	(80)[1]	1,056
5. W.New York/Pennsylvania	25,051	376	(80)[1]	301
6. Appalachian Plateau	16,190	13	--[4]	--
7. Blue Ridge/ Great Smoky Mts.	20,964	126	--	--
8. Coastal Plain	9,264	241	--	--
9. Lower Mississippi	13,075	170	--	--
10. Indiana/Kentucky	8,603	9	--	--
11. Central Wisconsin	12,141	583	(42)[2]	245
12. Wisconsin/Michigan Highlands	19,229	5,307	42	2,228
13. Northeast Minnesota	10,560	1,637	48	786
14. Central Minnesota	18,870	3,170	(48)[3]	1,522
TOTALS	245,024	17,059		9,423

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[1] In the absense of other data, alkalinities from the Adirondacks have been used.

[2] In the absense of other data, alkalinities from N. Wisconsin have been used.

[3] In the absense of other data, alkalinities from N. Minnesota have been used.

[4] No estimate is being made for regions with fewer than 250 lakes.

Table 4. Total first- and second-order stream resources present and at risk in the acid-sensitive regions of the Eastern United States. The confidence interval which would include 95% of replicated estimates is estimated to be ± 20%.

Region	Sensitive Area (mi²)	Total Streams (mi)		Percentage of Streams (± 10%) <200 μeq/ℓ	Calculated Total Miles (± 20%) of	
		1st Order	2nd Order		1° Streams at Risk	2° Streams at Risk
1. Eastern Maine	26,398	9,714	3,485	81	7,868	2,823
2. Western New Eng.	29,666	15,308	4,569	56	8,573	2,559
3. Adirondacks	14,066	5,289	3,024	(56)[1]	162	1,693
4. East Penna. S. New Eng.	20,947	8,400	2,556	38	3,192	211
5. W.New York/Penna.	25,051	7,114	1,678	55	3,913	373
6. Appalachian Plat.	16,190	7,350	2,299	(55)[2]	4,043	1,265
7. Blue Ridge/ Smoky Mts.	20,964	10,901	3,396	64	6,977	2,173
8. Coastal Plain	9,264	1,547	713	(43)[3]	201	92
9. Lower Miss.	13,075	5,374	1,255	(43)[3]	699	163
10. Indiana/Kentucky	8,603	2,805	989	(43)[3]	129	
11. Central Wis.	12,141	2,683	728	43	1,154	313
12. Wisconsin/Mich. Highlands	19,229	5,037	1,737	13	655	226
13. Northeast Minn.	10,560	1,637	475	(13)[4]	213	62
14. Central Minn.	18,870	4,831	2,529	(13)[4]	628	329
TOTALS	245,024	87,990	29,433		38,643	12,412

[1] In the absense of other data, alkalinities from W. New England and W. New York/Pennsylvania have been used.

[2] In the absense of other data, alkalinities from W. New York/Pennsylvania have been used.

[3] In the absense of other data, alkalinities from Central Wisconsin have been used.

[4] In the absense of other data, alkalinities from Northern Wisconsin have been used.

3,000 lakes and 23,000 miles of streams with alkalinity levels that can be described as already acid-altered. This corresponds to 18% of the lakes and 21% of the streams located within the 14 sensitive areas. See Tables 5 and 6.

Finally, we developed a simple model to estimate the effects on aquatic resources of three possible future acid deposition scenarios. As an underlying assumption, the model uses an empirical measure to project changes in lake and stream alkalinities given a change in sulfate deposition. This measure --the "alkalinity impact parameter" -- is based on both limited observations through time of alkalinity changes in areas where sulfate deposition has been increased or reduced, and on current theoretical understanding of the processes involved. Although not yet fully validated, the model suggests that lake and stream alkalinities are likely to respond to future changes in sulfate deposition.

For scenario #1, a 10% increase in sulfate deposition by the year 2000, the model projects that 4 to 15 percent of the most sensitive lakes and streams worsen in condition -- becoming either "acidified" or "extremely sensitive" to acid inputs. Under scenario #2, which provides for a 20% decrease in sulfate deposition by the year 2000, 10-25% of the most sensitive lakes and streams are estimated to experience some recovery -- i.e., "acidified" aquatic resources become "extremely sensitive" or "extremely sensitive" resources become "moderately sensitive". Scenario #3, which involved a 35% decrease in sulfate deposition by the year 2000, is estimated to result in some recovery for 16 to 41% of the most sensitive aquatic resources. (See Tables 7 and 8).

B. How Much Reduction in SO_4^{2-} Can Be Anticipated

One issue on which great uncertainty has been alleged concerns the recent trend downward in total SO_2 emissions, while the acidity of rainfall has remained relatively unchanged. The fact is that SO_2 emissions abatement is being matched by reduction in deposition of SO_4^{2-}, the principal acidifying agent. Acidity of rainfall has stayed about the same because of recent increases in nitric acid content in rainfall, acidity that is presently of less quantitative significance.

Table 5. An estimation of the "acid-altered" lake resources of the eastern United States combined for alkalinity classes I and II, using 1980 calculated alkalinity depression and "historic" area alkalinity distributions as a control. (Estimated confidence, ± 20%.)

Region	Total No. Lakes	(1980) No. Lakes in Alk. Class I & II	Historic No. Lakes Alk. Class I & II	(1980) No. Lakes Altered Alk. Class I & II
1	1425	456	43	413
2	1543	494	46	448
3	1139	456	34	422
4	1320	423	40	383
5	376	150	11	139
6	13	----	----	----
7	126	----	----	----
8	241	----	----	----
9	170	----	----	----
10	9	----	----	----
11	583	134	17	117
12	5307	1220	159	1061
13	1637	49	49	0
14	3170	95	95	0
TOTAL	17059	3477	494	2983

Total number of lakes altered, Class I and II: 2,983

Percentage of lakes altered: 18%

Table 6. An estimation of the "acid-altered" stream resources of the eastern United States combined for alkalinity classes I and II and 38% of III[1] using both calculated alkalinity depression and alkalinity distribution from untreated areas as a baseline or control. (Estimated confidence, ± 20%.)

Region	Total Stream Miles	1980 Miles in Class I & II plus 38% of III[1]	Historic Stream Miles in Class I, II + 38% of III	Stream Miles Altered, Class I, II + 38% of III
1	13,199	3,746	816	2,930
2	19,877	5,641	1,228	4,413
3	8,313	3,060	514	2,546
4	10,956	3,109	677	2,432
5	8,792	3,237	543	2,694
6	9,649	2,738	596	2,142
7	14,297	4,058	884	3,174
8	2,260	482	140	342
9	6,629	1,412	410	1,002
10	3,794	809	234	575
11	3,411	1,181	211	970
12	6,774	418	418	0
13	2,112	130	131	0
14	7,360	455	455	0
TOTAL	117,423	30,476	7,257	23,220[2]

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[1] Based on the calculated portion of alkalinity Class III streams (60/160) that is comparable to the Class I and II population of lakes (see discussion of Tables 12 and 13).

[2] Total stream miles altered, Class I, II and 38% of III: 23,220, representing 20% of the total first and second order stream resource.

Table 7. Estimated total changes in the status of lakes in alkalinity Classes I and II by the year 2000 in relation to total acid-altered lake resources in 1980 for Scenarios 1, 2 and 3.

Region		No. Acid Altered Lakes, 1980	Change in no. altered lakes, 2000		
			Scenario 1 (Increase)	Scenario 2 (Decrease)	Scenario 3 (Decrease)
1	Eastern Maine	413	19 - 38	57 - 114	91 - 182
2	Western New England	448	31 - 61	62 - 123	111 - 222
3	Adirondacks	422	31 - 62	80 - 159	137 - 273
4	East Pennsylvania S. New England	383	26 - 52	53 - 106	95 - 190
5	W. New York/Pennsylvania	139	13 - 25	34 - 68	56 - 113
11	Central Wisconsin	117	0 - 7	0 - 13	0 - 20
12	Wisconsin/Michigan Highlands	1,061	0 - 66	0 - 153	0 - 214
13	Northeast Minnesota	0	0 - 9	0 - 4	0 - 6
14	Central Minnesota	0	0 - 9	0 - 5	0 - 10
		2,983	120 -329	287 - 745	490 -1230
Percent of Acid-altered Lakes:			4 - 11	10 - 25	16 - 41

Table 8. Estimated total change in the status of 1st and 2nd order stream miles in alkalinity Classes I, II and 38% of III, by the year 2000 in relation to total acid-altered stream resources in 1980 for Scenarios 1, 2 and 3.

Region		1980 miles of altered streams Class I, II and 38% of III	Change in miles of altered streams, 2000		
			Scenario 1 (Increase)	Scenario 2 (Decrease)	Scenario 3 (Decrease)
1	Eastern Maine	2,930	147 - 295	228 - 457	365 - 731
2	W. New England	4,413	333 - 666	344 - 688	619 - 1,238
3	Adirondacks	2,546	184 - 369	374 - 748	641 - 1,282
4	East Pennsylvania/ S. New England	2,432	183 - 367	190 - 379	341 - 683
5	W. New York/ Pennslyvania	2,694	244 - 487	508 - 1,017	847 - 1,695
6	Appalachian Plateau	2,142	215 - 431	234 - 468	401 - 802
7	Blue Ridge/Great Smokey Mts.	3,174	239 - 479	297 - 594	495 - 990
8	Coastal Plain	342	20 - 40	32 - 64	51 - 102
9	Lower Mississippi	1,002	117 - 234	150 - 300	263 - 526
10	Indiana/Kentucky	575	67 - 134	75 - 150	140 - 279
11	Central Wisconsin	970	0 - 30	0 - 39	0 - 58
12	Wisconsin/Michigan Highlands	0	0 - 22	0 - 26	0 - 36
13	Northeast Minnesota	0	0 - 7	0 - 5	0 - 8
14	Central Minnesota	0	0 - 12	0 - 11	0 - 22
		23,220	1,749 - 3,573	2,432 - 4,946	4,163 - 8,452
Percent of Acid-altered Streams			8 - 15	10 - 21	18 - 36

Results in Table 9 and Figure 2 support this conclusion. The data in Table 9 show that SO_2 emissions through two northeastern regions have decreased appreciably since a peak in the 1965-70 period. Figure 2, based on the published results of Likens and associates at Hubbard Brook in central New Hampshire, shows that deposition of the principal acidifying agent, SO_4^{2-}, also peaked in the 1965-70 period and has been trending downward since then. Although current data at this site show the trend downward to be continuing, the projections for future SO_2 emissions are now upward.

C. What Actions are Warranted

Let me now address the question of how much emissions abatement is needed and how quickly it should take place. My experience in the intensive Ohio River Basin Energy Study (ORBES) has convinced me that it is not technically possible to plan and carry out an orderly reduction of 10,000,000 tons of SO_2 emissions within a decade. I believe this level of emission reduction is warranted, but we should recognize that it is feasible only over two decades even if we were to direct the principal emitters to begin developing their most cost effective strategies immediately.

Let me elaborate on this point and indicate other conclusions that go along with it. The Phase II report of the United States/Canada Assessment of Effects from Transboundary Air Pollution estimates that a "no-effect level" of acidic deposition is probably close to 25% of present acidic inputs in the most heavily impacted regions. This estimate is in general agreement with the recent National Academy of Sciences' report. Even with a 75% reduction, the remaining acidic input would be roughly 200 to 400% above our historic inputs of atmospheric sulfate. Thus, for purposes of defining the need, we should talk about a possible maximum 75% decrease in deposition. Since such a decrease could well be viewed as an unrealistic abatement goal, if undertaken all at once, or very quickly, let us consider looking at it in three steps.

One could think of a possible long-term 75% decrease in acidic deposition in three steps of perhaps 25% each. The decision process, and the

Table 9. HISTORICAL TRENDS IN SO_2 EMISSIONS

in 1000's tons
EPA - REGION I

State	1950	1955	1960	1965	1970	1975	1978
Conn.	138.3	139.1	241.6	457.6	317.3	191.0	112
Maine	37.8	45.6	70.2	97.0	82.0	67.8	66
Mass.	906.4	956.7	374.6	443.2	584.4	362.2	402.2
New Hamp.	73.3	89.7	29.1	41.2	95.9	75.4	67.8
Rhode Island	67.7	80.2	87.3	41.2	60.1	24.3	19.7
TOTAL	1213.5	1311.3	802.8	1080.2	1139.1	720.7	667.7
			EPA - REGION II				
New York	847.0	1126.0	1427.4	1645.4	1455.0	1079.0	1041.1
New Jersey	*1308.8	*1486.2	482.6	623.4	590.2	341.0	323.7
TOTAL	*2155.8	*2612.20	1910.00	2268.8	2045.2	1420.0	1364.8
			EPA - REGION III				
Delaware	105.4	136.0	196.1	217.8	223.4	193.6	188.2
D.C.	32.4	31.0	38.5	47.9	78.0	27.1	17.6
Maryland	398.9	515.5	518.2	588.1	467.7	322.3	357.3
Penn.	* 970.2	2138.4	2362.2	2546.8	2245.7	2130.8	1900.0
Va.	157.2	277.4	171.4	188.1	475.2	381.0	359.9
West Va.	243.5	617.8	529.7	776.8	979.7	1220.0	1049.5
TOTAL	*1907.6	3716.1	3816.1	4365.5	4469.7	4274.8	3872.3
			EPA - REGION IV				
Alabama	139.5	522.7	613.5	892.3	979.1	986.5	762.1
Florida	225.5	350.5	341.1	501.6	862.3	827.9	685.9
Georgia	119.9	163.6	198.2	303.0	410.4	571.4	707.0
Mississippi	46.9	43.3	41.1	44.6	79.4	193.0	264.3
Kentucky	113.1	404.8	631.1	914.0	1280.9	1466.8	1330.0
North Carolina	306.1	347.4	232.4	294.4	533.2	500.5	562.3
South Carolina	44.5	84.3	115.9	121.7	185.4	202.3	288.6
Tenn.	97.3	369.2	731.2	771.5	988.1	1141.9	1162.8
TOTAL	1092.8	2285.8	2904.3	3843.1	3318.5	3890.3	3763.0

Table 9. HISTORICAL TRENDS IN SO_2 EMISSIONS (Cont.)

State	1955	1960	1965	1970	1975	1978
		in 1000's tons				
		EPA - REGION V				
Illinois	*1172.1	2452.9	2791.4	2506.5	1950.6	1747.2
Indiana	174.2	1840.8	2180.3	1941.5	1980.0	1848.2
Mich.	702.7	1085.5	1521.7	1520.9	1450.6	1117.8
Minn.	536.4	391.8	419.8	450.7	382.3	379.0
Ohio	*344.9	2933.2	3181.2	3125.2	3271.2	3115.3
Wisc.	304.2	604.0	703.8	322.3	166.6	663.6
TOTAL	*234.5	9308.2	10798.2	9867.1	9201.3	8871.1
		OTHER STATES				
Arkansas	36.7	26.1	29.9	37.0	68.6	121.6
Iowa	258.0	364.5	440.8	370.2	314.0	385.0
Louisiana	261.2	219.4	268.7	318.0	295.1	359.0
Missouri	1155.1	582.6	674.9	1107.3	1174.3	1307.7
Texas	073.8	900.0	1074.3	1136.8	1123.8	1244.8

*Questionable Data

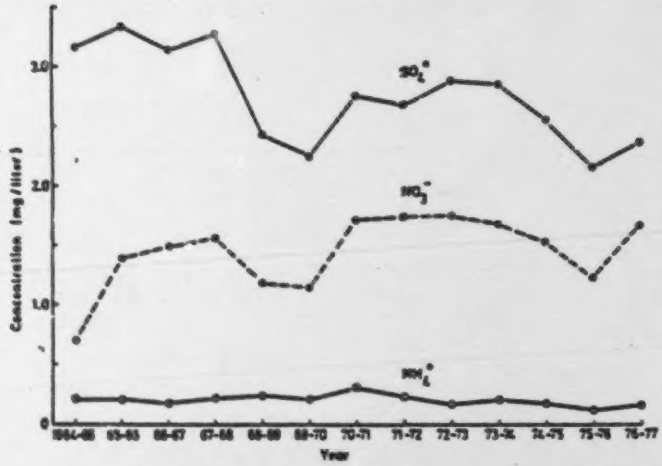

Figure 2. Annual weighted concentrations of $SO_4^=$, NO_3^- and NH_4^+ in precipitation at the Hubbard Brook Experimental Forest from 1964 to 1977.

cost-benefit analysis, then, could be incremental, with a first-step 25% abatement to begin now and be spread over at least a decade. During the decade, we could complete the new research contemplated under the U.S. National Plan and do a definitive cost-benefit analysis as to whether a second or third step in the sequence is, in fact, warranted.

Thus, in the context of the evidence from current research results, and in the milieu of a 10-year research program that is just beginning, it appears that govrnment should act now to take a first step toward restoration of aquatic resources and protection of forest productivity in the eastern United States. This first step could be made up of non-structural procedures such as least emissions dispatch and substitution of eastern low-sulfur coal. This would offer an opportunity to document the ensuing level of benefits without yet committing the industrial community to a large or poorly planned program of capital investment for abatement. Such a program will require at least five years to plan and review, and I suggest it would be desirable for the Congress to mandate the planning process now, and postpone a decision on its implementation until results from the accelerated acid rain research program are available. The Congress could then direct that the second step toward a 10,000,000 ton SO_2 abatement take place during the decade of the 1990's if research results and cost/benefit analysis so warrant. I do not view this proposal as a postponement of action now because full implementation of structural aspects of SO_2 abatement are unlikely to be accomplished before the 1990's by any legislative initiative.

D. Summary

On the basis of these recent results and evidence previously available to the Committee and the scientific community, I wish to state the following summary findings:

1. A broad range of significant alterations of land and water resources are being documented now that are almost certainly attributable to acidic deposition, and new evidence almost every month indicates more resources and the interests of more and more of the United States population are being affected.

2. The evidence for decrease of deposition of acidic substances corresponding with evidence of decreased emissions indicate that SO_2 abatement can be expected to provide relief from SO_4^{2-} deposition.

3. The 10,000,000 ton SO_2 emissions reduction over ten years now being considered in draft legislation could be viewed in two steps of 5,000,000 tons each, with a possible third step to bring us to an indicated goal of 75% reduction in SO_4^{2-} deposition. I believe we clearly know enough now to take at least one step toward protection of vital natural resources in the effected areas.

4. For reasons of the time required to evaluate new construction, coal-washing, and retrofitting options, and to schedule retirements of older non-confirming facilities, the legislation probably should mandate only a 5,000,000 ton reduction in the next ten years, mandate planning for structural abatement steps during the 1990's, and schedule a decision by the Congress on this second step in six to seven years when more results from the current acid rain research program is available. A third step in abatement should be considered at the end of 20 years when we can assess more fully the overall costs and benefits of such a program.

CAST

COUNCIL FOR AGRICULTURAL SCIENCE AND TECHNOLOGY

Headquarters: 250 Memorial Union, Ames, Iowa 50011 Telephone 515-294-2036 or 2903

June 10, 1982

American College of Veterinary Toxicologists
American Dairy Science Association
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American Meat Science Association
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Crop Science Society of America
Institute of Food Technologists
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Plant Growth Regulator Society of America
Poultry Science Association
Rural Sociological Society
Society of Nematologists
Soil Science Society of America
Southern Weed Science Society
Weed Science Society of America
Western Society of Weed Science

Mr. Paul Chimes
Committee on Environment and Public Works
4202 Dirksen Senate Office Building
Washington, D.C. 20510

Dear Mr. Chimes:

We have just learned of the May 25 and 27 hearings on "acid rain" that were sponsored by the Committee on Environment and Public Works. We are writing because of our concern that the Committee be aware of the full range of scientific information available on the subject and that the information be presented in practical perspective as an aid to understanding and decision-making.

In agriculture, soil acidity was a problem long before the dawn of science and the industrial age. Soil chemists and soil fertility specialists have been studying soil acidity -- its nature, development, measurement, effects, and alleviation -- for more than a half century. A summary and interpretation of some of their findings as applied to the acid rain issue is found in the enclosed paper, which we submit for inclusion in the hearing record.

According to a summary of data just released from the National Atmospheric Deposition Program (Regional Project NC 141), the chairman of which is Ellis Cowling, a participant in the hearings on May 27, the annual deposition of sulfate sulfur from atmospheric sources among the 96 test stations in the United States (including Alaska and Hawaii) ranged from about 1 to 24 pounds per acre in calendar year 1980. To aid in putting this finding in perspective, we would note that the quantities of sulfate sulfur required by moderate to high yields of crops range from 8 to 85 pounds per acre. If all the sulfate sulfur deposited from atmospheric sources were received as sulfuric acid, the maximum addition of 24 pounds per acre in 1980 would be neutralized by about 75 pounds of calcium carbonate. The amount of ground limestone containing this quantity of calcium carbonate could be purchased for addition to soils or lakes for a few cents.

A CAST task force is preparing a report on "Acid Precipitation as it Affects Agriculture, Forestry, and Aquatic Biology," and we expect to send copies to Committee members when it is published.

Sincerely,

Charles A. Black

Charles A. Black
Executive Vice President

cc: Curtiss Moore

Editor's Forum

Additional Facts You Should Know About "Acid Rain"

Summary

1. The sulfur and nitrogen in acid rain are plant nutrients.
2. Soils and lakes become acid from natural causes as well as from acid rain.
3. The amount of acidity produced in agricultural soils by acid rain is small in relation to the acidity produced there by other causes.
4. Lakes that have become acid and fishless because of acid rain can be neutralized and made suitable for fish, should the presence of fish justify the investment.

Almost all precipitation is acid and has been so since preindustrial days. The term "acid rain," as used currently, refers to precipitation with acidity greater than that corresponding to pH 5.7. Acidity of pH 5.7 is produced in water by the carbonic acid that forms when water equilibrates with atmospheric carbon dioxide. The excess acidity is associated largely with sulfuric and nitric acids that result in part from human activities.

EPA (Tirpak et al., 1979) describes the situation as follows in a recent research summary:

> As a result of the combustion of tremendous quantities of fossil fuels such as coal and oil, the United States annually discharges approximately 50 million metric tons of sulfur and nitrogen oxides into the atmosphere. Through a series of complex chemical reactions these pollutants can be converted into acids, which may return to earth as components of either rain or snow. This acid precipitation, more commonly known as acid rain, may have severe ecological impacts on widespread areas of the environment.
>
> Hundreds of lakes in North America and Scandinavia have become so acidic that they can no longer support fish life. More than 90 lakes in the Adirondack mountains in New York State are fishless because acidic conditions have inhibited reproduction. Preliminary research indicates that the yield from agricultural crops can be reduced as a result of both the direct effects of acids on foliage, and the indirect effects resulting from the leaching of minerals from soils. The productivity of forests may be affected in a similar manner.

In the words of Gage, who wrote the foreword to the same publication,

> Acid rain may be one of the most significant environmental problems of the coming decade. It poses new challenges to the full development of our forest, agricultural, and aquatic resources; and to the use of fossil fuels as an energy source.

The 1979 EPA research summary from which the foregoing quotations were taken deals only with the hazards of acid rain. In a more recent EPA publication (Laska et al., 1980) that is said to tell "what we know — and don't know — about acid precipitation," there are approximately 245 inches of text. Of these, 3¼ inches are devoted to liming of acidified lakes with the conclusion "that this practice would only be feasible for small ponds and streams," and 1¼ inches are devoted to elaboration on the qualified statement "that nitrogen and sulfur in precipitation can, in limited concentrations, be a beneficial nutrient to some ecosystems."

In view of the limited coverage of subject matter other than hazards in educational information published by EPA, and in view of the extensive body of information related to soil acidity and plant nutrition that has been accumulated over many years by agricultural scientists, there remains a need to have the relevant knowledge explained to provide a broader perspective of the acid rain issue than is provided by EPA. The few paragraphs that follow are intended only to call attention to what are considered salient points and not to explain them in detail or to imply that acid rain poses no hazards.

Fact number one

The sulfur and nitrogen in acid rain are plant nutrients.

Plants respond unfavorably to excessive acidity in rainfall (Cowling, 1978) as well as to excess fertilizer salts applied to the foliage or to the soil. Plant tolerance to a given addition of sulfate and nitrate to the foliage is less if these nutrients are added as acids than as salts.

The sulfur and nitrogen supplied in the rainfall are of course unevenly distributed, like rainfall itself. Striking historical examples exist in relatively small areas near certain smelters where the vegetation was killed and the soils were strongly acidified.

Nonetheless, sulfur and nitrogen are essential nutrients for all plants. Moreover, like the sulfur and nitrogen supplied in fertilizers, atmospheric contributions of sulfur and nitrogen are utilized by plants as nutrients and are of economic value if the amounts supplied are sufficient but not excessive. Plants absorb nutrients through the foliage as well as the roots.

Sulfur deficiencies for plants have been found in 32 of the 50 states (Anonymous, 1975). None of these states is in the Northeast, however, presumably because the concentrations of atmospheric sulfur in that part of the country are now sufficient to meet the needs. Deficiencies of sulfur occur in all the southeastern states, where additions of sulfur from the atmosphere are less. Alabama has a law requiring that all mixed fertilizers sold in the state contain a minimum of 3 percent of sulfur.

According to Terman (1978), the quantities of sulfur required by moderate to high yields of crops range from 8 to 85 pounds per acre per year. These requirements correspond to the amounts of sulfur that would be added each year in 22 to 234 inches of acid rain of pH 4.0 such as that falling in the Adirondack Region of New York (Likens and Bormann, 1974) if all the sulfur in the rain were present as sulfuric acid and if all the acidity of the rain were a consequence of sulfuric acid.

Noggle (1979) conducted field experiments to evaluate the contribution of atmospheric sources of sulfur to plant nutrition and concluded in an internal Tennessee Valley Authority report cited here by the author's permission that up to 50 percent of the sulfur required for maximum crop production on many of the soils in the Tennessee Valley States is absorbed from atmospheric sources (precipitation plus direct absorption from the air). He estimated that the annual value of the atmospheric sulfur in that area is about 40 cents per acre on the basis of the fertilizer sulfur it replaces or $20 per acre on the basis of the crops it produces.

Noggle used a figure of 5 to 6 cents per pound for the cost of fertilizer sulfur. This is the cost of the most economical forms of sulfur. The cost of a pound of fertilizer sulfur as calcium sulfate derived from limestone scrubbers used to desulfurize flue gases in power plants would be considerably more — about $0.30 to $3.50, depending upon the size of the plant and the sulfur content of the coal (C. David Stevenson, Energy Demonstrations and Operations Group, Tennessee Valley Authority, Muscle Shoals, Ala., personal communication, 1981).

Additional research has been reported from Wisconsin. Hoeft et al. (1972) found that 44 percent of the sulfur in alfalfa was derived from the atmosphere when the plants were grown in acid-washed sand supplied with a nutrient solution containing enough radiotracer-tagged sulfate to produce almost the maximum yield attainable by sulfate addition. The proportion derived from the atmosphere exceeded 44 percent under conditions of sulfur deficiency in the nutrient medium available to the roots. In this work, rainfall was not a source of sulfur because the plants were grown in a greenhouse and were protected from rain.

Nitrogen is the limiting nutrient of first importance for growth of both crop plants and forests. The natural supply of nitrogen limits plant growth on most of the cropland and forest land in the United States. The amount of chemically combined nitrogen supplied to plants in acid rain decreases the need for nitrogen fertilizer, but the amount supplied from atmospheric sources[1] is small. Pearson and Fisher (1971) reported that additions of nitrogen in the precipitation in northeastern United States averaged 2.44 pounds per acre annually, which corresponds to an addition of acid equivalent to 9 pounds of calcium carbonate per acre annually. This addition of nitrogen is relatively small in comparison with the average annual application of about 50 pounds of fertilizer nitrogen per acre of U.S. cropland and in comparison with the requirements of plants for nitrogen, which may amount, for example, to 150 pounds per acre for a 100-bushel crop of corn (Tisdale and Nelson, 1956).

Further information that is useful in placing in perspective the plant nutrient aspects of acid rain is found in papers by Kamprath (1972), Ohlrogge (1971), Rutter et al. (1976), Tabatabai et al. (1981), and Terman (1978). The paper by Terman is a comprehensive literature review. Tabatabai et al. (1981) summarized research data in the North Central Region and concluded that the current levels of nitrogen, sulfur, and phosphorus received in the precipitation in that region are beneficial to agricultural production.

Fact number two

Soils and lakes become acid from natural causes as well as from acid rain.

Farmers have been contending with the effects of soil acidity since before the dawn of science and industry — acidity associated with atmospheric effects. Soils in dry regions are generally neutral or alkaline. Those in humid regions are generally acid as a result of natural processes (Jenny and Leonard, 1934; Black, 1968).

According to Patrick et al. (1981), records indicate that naturally acid lakes and ponds have existed since the 1860s in New England and New Jersey, and similar shallow lakes and ponds occur also in the Southeast. Such lakes, with a pH of 3.4 to 4.5, contain many kinds of algae as well as some crustaceans and aquatic insects. Characteristic fish are found, although they are not as diversified as those in less acid lakes.

The acidity of the water in a given lake normally undergoes an annual cycle, becoming more acid during the cold season and less acid during the warm season. This cycle is associated with the production and decomposition of aquatic vegetation (and other organic matter), the rates of which are not equally affected by the changes in temperature and other conditions during the year[2].

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[1] According to EPA (Gage, 1980), "fires and other natural occurrences result in about 10 times the amount of NO_x generated by man. ..." The "other natural occurrences" include lightning discharges and evolution of nitrogenous gases from soils and waters.

[2] As aquatic vegetation grows, it removes from the water greater numbers of equivalents of bicarbonate, nitrate, sulfate, and phosphate anions than of the associated cations, including calcium, magnesium, potassium, and sodium. The result is that during the warm season when the vegetation is growing most rapidly the water becomes less acid or more alkaline. This process causes the water in some lakes to become saturated with calcium carbonate, and calcium carbonate is precipitated and settles to the bottom. Decomposition of organic matter also proceeds more rapidly at high than at low temperatures. During the cold season when growth of aquatic vegetation is curtailed, however, there is some continuing release of the carbon, nitrogen, sulfur, and phosphorus that were incorporated into proteins and other organic compounds by the aquatic vegetation during the preceding warm season or in earlier annual cycles. These nutrients are released into the water as bicarbonate, nitrate, sulfate, and phosphate anions in excess of the equivalents of calcium, magnesium, potassium, and sodium ions released. The excess of anions is associated mostly with hydrogen ions as carbonic, nitric, sulfuric, and phosphoric acids. The water then becomes more acid. If calcium carbonate was precipitated during the summer cycle of vegetative growth, some of it dissolves. There are also additional complications associated with the oc-

Acid rain hastens the acidification of both soils and lakes. Lakes are acidified more easily by acid rain than are soils because (1) the buffering capacity of water is much smaller than that of soil solids or lake sediments, (2) the ratio of water to solids is much greater in lakes than in soils, and (3) the time required for the acids in the water to equilibrate with the less acid solids is greater in lakes than in soils.

In regions of alkaline to slightly acid soils, lake sediments often are rich in calcium carbonate and related carbonate minerals (Kelts and Hsu, 1978). Through equilibration of the water with carbonate minerals and soil materials high in pH in the bottom sediments, such lakes can neutralize considerable amounts of added acid. In regions of moderately acid and strongly acid soils, lake sediments generally can neutralize only relatively small amounts of added acid because the sediments lack the acid-buffering capacity of the carbonate minerals.

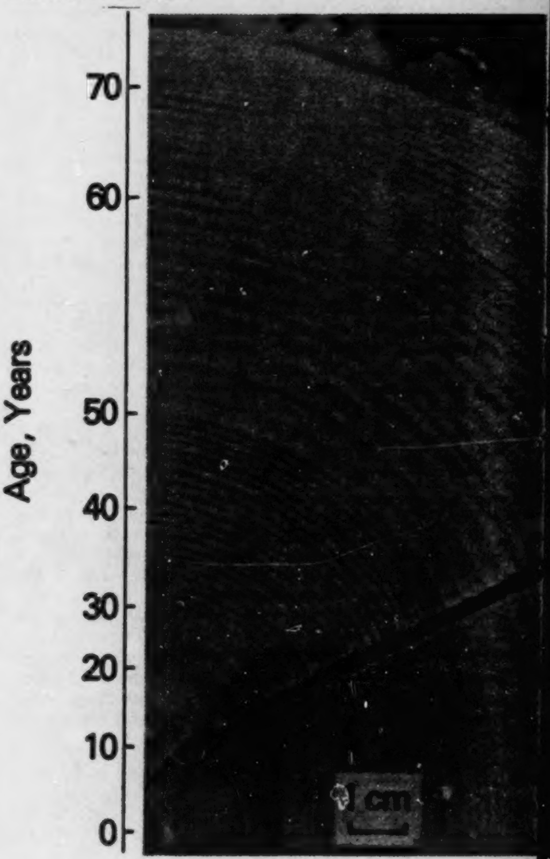
Fact number three

The amount of acidity produced in agricultural soils by acid rain is small in relation to the acidity produced there by other causes.

The quantities of acidity added in acid rain are significant. The greatest additions of sulfur and nitrogen to soils from the atmosphere reported in the review by Ficke (1977) were in Knoxville, Tenn., where the calcium carbonate equivalent of the acidity was 83 pounds per acre annually.[3]

Nonetheless, the quantities of acidity added currently in acid rain are relatively small in comparison with the increases in acidity of agricultural soils that were occurring long before the sharp increase in emissions of oxides of sulfur and nitrogen after 1960 to which Likens (1976) and others have attributed part of the acidity of current U.S. rainfall. For example, in Illinois (C.H. Farnham, Department of Agronomy, University of Illinois, personal communication, 1943), soil analyses for exchangeable calcium made in 1933 indicated that the rate of loss of a single application of 4 tons of limestone made in a field experiment in 1912 had averaged 380 pounds per acre annually. In Connecticut, Brown and Munsell (1936) estimated from the rate of change of soil pH values following a single limestone application of 4 tons per acre in 1914 that "an average of about 300 pounds of limestone per year might maintain this or similar soils at a given pH." In Ohio (Earl E. Barnes, Department of Agronomy, Ohio State University, personal communication about 1943), application of 500 pounds of limestone per acre at 3-year intervals (about 170 pounds per year) was found sufficient to maintain the soil pH at an approximately constant level above that of the unlimed soil. Application of 1,000 pounds of limestone per acre at 3-year intervals (about 330 pounds per year) caused the pH of the soil to rise gradually,

Cross section of the trunk of a white ash tree from the Harvard Black Rock Forest in New York illustrating the effect of a single heavy application of nitrogen fertilizer. The tree was apparently 50 years of age in 1935 when the area on which it was growing was treated with 864 pounds of nitrogen per acre as an equal-weight mixture of ammonium sulfate and sodium nitrate (Mitchell and Chandler, 1939). No fertilizer was applied subsequently. Note the marked increase in thickness of the annual rings indicating greater growth for a number of years after fertilization. The theoretical acidity produced in the soil by the ammonium sulfate supplied in the fertilizer application would be equivalent to the acidity in 3062 inches of acid rain of pH 4 and would require 3472 pounds of calcium carbonate per acre for neutralization if the fertilizers had been pure compounds applied in the absence of vegetation. In the presence of vegetation, the acidity probably would have been less than this, as explained in part in footnote 4. The cross section from which the photograph was made was supplied by Dr. R. F. Finn.



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currence of zones of water at different depths in deep lakes because of slow mixing. Growth of aquatic vegetation occurs mostly near the surface and decomposition mostly at greater depths.

[3] The calculations of acidity of the precipitation at Knoxville, Tennessee, are based on the maximum values reported by Ficke (1977). All the nitrogen in the precipitation is assumed to transform to nitric acid in the soil. Cation equivalents are then subtracted from anion equivalents to obtain the net acidity, which is represented as the calcium carbonate equivalent.

indicating that this amount of limestone was more than enough to neutralize the acidity developed in the soil.

According to the U.S. Bureau of Mines (1979), 33,240,000 tons of ground limestone were sold for agricultural purposes in the United States in 1978. This amounts to 160 pounds per acre of all cropland. Because much of the cropland needs no limestone, the average application to the land in the humid region that does receive limestone is much greater.

At present, one of the important causes of acidity in soils is addition of nitrogen fertilizer. The average annual application of fertilizer nitrogen in the United States is about 50 pounds per acre of cropland. Applied as anhydrous ammonia, urea, or ammonium nitrate — three commonly used nitrogen fertilizers — 50 pounds of nitrogen would oxidize in the soil to nitric acid that would require 179 pounds of calcium carbonate or its limestone equivalent for neutralization. Some crops are fertilized much more heavily. Coastal bermudagrass, for example, generally receives 200 to 300 pounds of nitrogen per acre annually when grown for hay and up to 600 pounds per acre annually when used to produce pellets for chicken feed. The amount of nitric acid produced in the soil is proportional to the amount of nitrogen applied; 600 pounds of nitrogen would produce nitric acid equivalent to just over a ton of calcium carbonate.[4]

A second important cause of soil acidity is fixation of atmospheric nitrogen by leguminous crops. For example, Nyatsanga and Pierre (1973) calculated on the basis of their experimental data that a good crop of alfalfa that fixes 241 pounds of nitrogen per acre would produce acidity in the soil equivalent to 535 pounds of calcium carbonate per acre.[5]

McFee and Kelly (1977) and McFee (1978) have reviewed the effects of acid rain on soils.

Fact number four

Lakes that have become acid and fishless because of acid rain can be neutralized and made suitable for fish, should the presence of fish justify the investment.

An application of 272 pounds of powdered calcium carbonate or its equivalent per acre of surface area of an acid lake with a pH value of 4.7[6] would neutralize the acidity caused by nitric, sulfuric, and hydrochloric acids in the water to a depth of 100 feet. This amount of calcium carbonate equivalent can be purchased as ground limestone for about 50 cents. Additional quantities of calcium carbonate would be required to neutralize suspended acid organic matter and clay and to neutralize acid bottom sediments. These quantities cannot be calculated from the pH of the water, but they may be of the order of those needed to neutralize acid agricultural soils of comparable pH values, namely, several tons per acre. The calcium carbonate treatment would need to be repeated at intervals, as is true for acid agricultural soils.

Once the acidity of the bottom sediments has been neutralized, the annual additions of calcium carbonate required to neutralize the acidity falling on lakes of the Adirondack Region as acid rain would be 41 to 59 pounds per acre per year.[7] In practice, these amounts might need to be increased several fold to neutralize the additional water that runs into the lakes from the surrounding areas. —CHARLES A. BLACK, *Executive Vice President, Council for Agricultural Science and Technology; and Distinguished Professor and Collaborator, Iowa State University, Ames, Iowa.*

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[4] The theoretical requirement of 3.57 pounds of calcium carbonate to neutralize the nitric acid produced in soil by addition of 1 pound of fertilizer nitrogen supplied as urea or ammonium nitrate, for example, applies when plants are not present. It applies also when plants are present but when a long enough time has elapsed for the organic matter they produce to decompose, releasing in the soil as inorganic cations and anions the elements the plants absorbed as inorganic cations and anions from the soil. Plants influence the effect of nitrogen fertilizers on soil acidity because they absorb unequal numbers of cation equivalents and anion equivalents. Nitrate is generally the anion absorbed in greatest quantity. Most crop plants take up more equivalents of anions than of cations. As a consequence, the acidity developed in the soil from nitrogen fertilization in the presence of most crops is less than the theoretical value. See Pierre et al. (1970) for data showing the effect of different crops on the acidity produced in the soil by addition of ammonium nitrate.

[5] If the alfalfa were to be incorporated in the soil and allowed to decompose, releasing as inorganic anions and cations the elements it absorbed from the soil plus the nitrogen it fixed from the atmosphere, the fixed nitrogen would have an acidifying effect like that of the same amount of fertilizer nitrogen added as urea or ammonium nitrate, absorbed by the plants, and then returned to the form of nitrate in the soil when the crop residues decompose. The ratio of calcium carbonate to nitrogen in the example differs from the theoretical value of 3.57 pounds of calcium carbonate per pound of nitrogen for reasons explained in footnote 4.

[6] pH 4.7 has been chosen as a basis for calculation because, according to EPA (Tirpak et al., 1979), the average pH of Adirondack lakes in 1975 was about 4.7. The calculations relating acidity to pH values are based on the assumption that the acids are completely dissociated. This is a good first approximation for acidities of the intensity of those found in acid rain and caused by nitric, sulfuric, and hydrochloric acids.

[7] The calculated addition of 41 to 59 pounds of calcium carbonate per acre per year is based on annual precipitation of pH 4.0 (Likens and Bormann, 1974) totaling 36 to 52 inches. (One inch of acid rain of pH 4 would be neutralized by about 1.1 pounds of calcium carbonate per acre.) The nitrogen present as ammonium in the precipitation would require an additional quantity of calcium carbonate or limestone because it is transformed to nitric acid in aerated soil and water. The additional quantity of calcium carbonate generally would be negligible in comparison with the quantity of acidity in the water that runs into the lakes from the surrounding areas, however, because the number of chemical equivalents of ammonium in the nitrogen in acid rain in northeastern United States is small in comparison with the number of chemical equivalents of sulfate plus nitrate plus chloride with which most of the measured acidity is associated (Pearson and Fisher, 1971).

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June 11, 1982

Mr. Paul Chimes
Committee on Environment and Public Works
4202 Dirksen Senate Office Building
Washington, D.C. 20510

Dear Mr. Chimes:

I wish to enter the enclosed publication on "Nutrient Concentrations and Accumulations in Precipitation Over the North Central Region" in the record of the "acid rain" hearings sponsored by the Committee on Environment and Public Works on May 25 and 27.

Acid rain is a natural phenomenon, and under normal conditions acid rain should have no detrimental effects on soils or on agricultural and forest production. Sulfur is one of the trace substances always found in the atmosphere. It is well known that high concentrations of sulfur dioxide in air are harmful to plants and animals, including man. These harmful effects, however, are emphasized much more often than are the beneficial effects of moderate or low concentrations on crops. In many areas, the amounts of nitrogen and sulfur added in precipitation are small compared with those required by agricultural and forested ecosystems. Therefore, nutrient deposition by precipitation should be beneficial to crop production in many areas.

The enclosed publication is a result of the combined efforts of the soil scientists at the state universities in the North Central Region serving on the technical committee of Regional Project NC-98. The data show that, in general, the annual amounts of inorganic nitrogen deposited in the North Central Region range from 5 to 20 kg per hectare. Of these amounts, 50% is in the ammonium form and the other 50% is in the nitrate form in Iowa, but generally more ammonium nitrogen than nitrate nitrogen is deposited in this region. The concentration of sulfate sulfur varies among the sites and seems to be high during fall and winter and low during spring and summer. The annual deposition of sulfur ranges from 5 to 15 kg per hectare per year. The concentrations of soluble phosphorus in the form of phosphate are very low; they range from 0 to 120 micrograms per liter. The annual deposition of phosphorus is insignificant compared with the amounts present in soils and added in fertilizers; it ranges from less than 0.1 to as much as 1 kg per hectare per year. Therefore, it is concluded that current levels of nitrogen, sulfur, and phosphorus (especially sulfur) in precipitation in this region are beneficial to agricultural production. This is especially true for agricultural and grassland ecosystems that receive little or no fertilizer.

If you wish additional information before the report on the hearings is issued, please let me know.

Sincerely,

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Professor of Soil Chemistry

cc: Mr. Curtiss Moore

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Nutrient Concentrations and Accumulations in Precipitation Over the North Central Region

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Indiana
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and the United States Department of Agriculture, cooperating

Agriculture and Home Economics Experiment Station
Iowa State University of Science and Technology, Ames, Iowa

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SUMMARY

The chemical composition of precipitation and its effect on soils, vegetation, and aquatic life have received considerable attention in recent years. This report was prepared to pool the information available in the states of the North Central Region on nutrient concentrations and accumulations by precipitation. In addition, comparison was made of emission of particulates, SO_x, NO_x, CO, and hydrocarbons from various sources in each state in the study region. Results showed that, although emission of SO_x, NO_x, and particulates varies greatly among the states, the greater emissions are in Ohio and the least in North Dakota and South Dakota. Nitrogen (NH_4^+ and NO_3^-), sulfur (SO_4^{2-}), and phosphorus (PO_4^{3-}) concentrations and accumulations by precipitation in these states are very similar. Generally, the annual inorganic N deposition ranged from 5 to 20 kg/ha. Of these amounts, 50% was in the NH_4^+ form and the other 50% in the NO_3^- form in Iowa, but generally more NH_4-N than NO_3-N is deposited in this region. The concentration of SO_4-S varied among the sites and seemed to be high during fall and winter and low during spring and summer. The annual deposition of S ranged from 5 to 15 kg/ha per year. The soluble PO_4-P concentrations were very low; they ranged from 0 to 120 μg/l. The annual deposition of P was insignificant compared with that present in soils and added in fertilizers; it ranged from < 0.1 to 1 kg/ha.

Insufficient data are available on pH of precipitation in this region, but the limited information indicates that pH of precipitation is slightly alkaline (pH = 6) in Iowa, Nebraska, and one site (Lamberton) in Minnesota and slightly acid (pH, 4 to 5) in Illinois, Michigan, one site (Marcell) in Minnesota, and Ohio compared with that expected (pH = 5.7) for precipitation in equilibrium with normal CO_2 in the atmosphere.

It is concluded that current levels of N, S, and P (especially S) in precipitation in this region are beneficial to agricultural production. This is especially true for agricultural and grassland ecosystems that receive little or no fertilizers.

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Nutrient Concentrations and Accumulations in Precipitation Over the North Central Region

M. A. Tabatabai, R. E. Burwell, B. G. Ellis, D. R. Keeney,
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D. R. Timmons, E. S. Verry, and E. M. White

INTRODUCTION

The many facets of plant nutrients (e.g., N, P, and S) in the biosphere have become major environmental issues within the past decade. This concern is justified because of the increasing contamination of air and water resources by various substances on local and regional levels, especially in areas close to point sources. Little information is available, however, on variation in the amounts and concentrations of some of the substances present in air and natural water in various parts of the United States. Such information is essential for a better understanding of the transport and perhaps the fates of pollutants in the biosphere.

The atmospheric component of the N and S cycles often can be a significant part of the various pools of their respective cycles (Allison, 1965; Erickson, 1963; Feth, 1966; Gambell and Fisher, 1964; Meetham, 1960; Robinson and Robbins, 1970), but the atmospheric component of the P cycle seems to be of minor significance to the cycling of this element in the environment. Among the various chemical elements present in precipitation (e.g., N, S, K, Cl, and Ca), N and S deserve special attention because N added by precipitation may contribute to nitrate pollution of surface and ground water. Sulfur and N may cause acid rain that can lead to increased leaching from soils of Ca and other nutrient elements, deterioration of aquatic ecosystems, damage to vegetation and buildings, and other agricultural and urban problems. On the other hand, the limited amounts of N and S brought down by precipitation might be useful to meet crop requirements for these elements in areas where soils have limited supplies of N and S (Allway et al., 1937; Erdman, 1923; Olson et al., 1973; Schuman and Burwell, 1974; Tabatabai and Bremner, 1972; Walker, 1969; Widdowson and Hanway, 1974).

Normal water in the atmosphere in equilibrium with prevailing CO_2 pressure will have a pH of about 5.7 (Barrett and Brodin, 1955), but much lower pH values (*ca.* 3) have been reported for precipitation in the northeastern United States. The low pH values of precipitation have been considered to indicate air pollution (Likens and Bormann, 1974).

Nitrogen is the most plentiful element in the atmosphere. It plays a key role in the life of all living organisms. There are several N compounds in the atmosphere. These include N_2O, NO, NO_2, NH_3, and ammonium (NH_4^+) and nitrate (NO_3^-) aerosol. Large portions of the NH_3 and NO_x in the atmosphere may originate from biological processes, but the concentrations of these gases in the air are greatly affected by industrial activities, automobile traffic, and feedlot operations (Elliott et al., 1971; Hutchinson and Viets, 1969; Robinson and Robbins, 1970). Of the eight possible oxides of nitrogen (N_2O, NO, N_2O_3, NO_2, N_2O_4, N_2O_5, NO_3, and N_2O_6), only three (N_2O, NO, and NO_2) are important constituents of the atmosphere. Of these three, the most plentiful in the atmosphere is the relatively inert N_2O. Nitrogen dioxide present in the atmosphere, however, can react with water vapor to form NHO_3, which, in turn, reacts with NH_3 or cations associated with particles in the air and forms nitrate salts, such as ammonium nitrate, which is brought down by precipitation. The major reactions involving the various gaseous N compounds are oxidation reactions of both NH_3 and NO_2 to form nitrates and neutralization of NH_3 to form $(NH_4)_2SO_4$ and NH_4NO_3 aerosols. Atmospheric particles frequently are found to contain $(NH_4)_2SO_4$, and its formation from NH_3 and SO_2 in the atmosphere probably is a significant factor in the scavenging of SO_2.

The major sources for the gaseous N compounds are biological action and organic decomposition in the soil and, to a lesser extent, in the ocean. Only NO and NO_2 are emitted as pollutants, at an estimated annual worldwide rate of about 50 x 10^6t (Robinson and Robbins, 1968). It has been estimated that, on a global basis, about 99% of the total atmospheric combined N is derived from biological processes and only 1% from combustion (Robinson and Robbins, 1970). The residence times for all the N compounds except N_2O are only a few days. For N_2O, the residence time has been calculated to be 70 years if there is no loss in the biosphere. Biological reaction, however, may reduce the residence time to about 1 to 3 years (Robinson and Robbins, 1968).

Stewart (1970) found that a significant portion (90%) of the urea N excreted by animals in feedlots may find its way to the air as NH_3. An appreciable fraction of atmospheric NH_3, in turn, is absorbed by soil, plant, and water surfaces in the vicinity of feedlots (Elliott et al., 1971; Hutchinson and Viets, 1969). It has been shown that there is a tendency for more NH_3 to be contained in precipitation near feedlots, but it seems that the amounts brought down by precipitation are insignificant compared with those directly absorbed by soil and water surfaces (Hoeft et al., 1972; Hutchinson and Viets, 1969).

Sulfur is one of the trace substances always found in the atmosphere. Sulfur enters the atmosphere as SO_2, H_2S, H_2SO_4, and various sulfates (SO_4^{2-}). In unpolluted air, S occurs primarily in three compounds, SO_4^{2-} in aerosol and SO_2 and H_2S gases. Hydrogen sulfide in the air normally is oxidized to SO_2, which in turn, is oxidized to SO_3. Sulfur trioxide dissolves in water droplets to form H_2SO_4, which may react further to form sulfate salts, such as $(NH_4)_2SO_4$. Both the H_2SO_4 and sulfate salts thus formed exist in air as an aerosol and are removed by precipitation and, to a lesser extent, by gravitational settling. It is estimated that a given volume of SO_2 that enters the air will be removed by these mechanisms, as acid or salt, in a time ranging from 5 days to 2 weeks (Erickson, 1963).

There are several sources for atmospheric S, including sea spray, H_2S and volatile sulfides released from marshlands and sea, and SO_2 released by burning S-containing fuels (Coleman, 1966; Erickson, 1963). Junge's (1960) work on the S budget of the global atmosphere indicates that, excluding the SO_4^{2-} in sea salt particles, 30% of the atmospheric S is of anthropogenic origin. Other estimates indicate that the S released from spray and S-containing fuels accounts for about 12 and 11%, respectively, and that the other 77% is released as H_2S from marshlands and sea (Erickson, 1963). Hoeft et al. (1972) have shown that atmospheric SO_2 levels in both rural and urban locations in Wisconsin tend to be seasonal, low in summer and increased markedly in winter. They attributed this to the burning of S-containing fuels in winter and slow release of S from soil and biological reactions during this time. A similar observation has been reported for SO_4^{2-} levels in preciptation over Iowa (Tabatabai and Laflen, 1976).

It is well known that high concentrations of SO_2 in air are harmful to plants and animals, including man. These harmful effects, however, are emphasized much more often than are the beneficial effects of moderate or low concentrations on crops. In many areas, precipitation adds small amounts of N and S compared with those required by agricultural and forested ecosystems. Within the past several years, many sampling stations, especially in the North Central Region, were established to collect and analyze precipitation samples for plant nutrients and, in some instances, for pH. The objective of this regional publication is to pool all the data available in the North Central Region on concentrations and amounts of nutrients in precipitation in this region. The results available are compared with the amounts of nutrients required by crops, the annual addition by fertilizers to agricultural land, and the annual amounts of pollutants emitted from point (as of October 1979) and nonpoint (as of June 1979) sources in the states of the study region.

The data summarized in this publication were contributed from studies in Indiana by D. W. Nelson, in Iowa by R. E. Burwell and M. A. Tabatabai, in Michigan by B. G. Ellis, in Minnesota by G. W. Randall, D. R. Timmons, and E. S. Verry, in Nebraska by R. A. Olson, in Ohio by F. Haghiri and T. J. Logan, in South Dakota by E. M. White, and in Wisconsin by D. R. Kenney.

PROCEDURES

The NC-98 committee developed a standard reporting form for summarizing the data available on nutrients in precipitation from each site in the region. Copies of the form were submitted to each state representative. Data were received from Indiana, Iowa, Michigan, Minnesota, Nebraska, Ohio, South Dakota, and Wisconsin. Information on the analytical procedures used was submitted with the data. Ammonium-N and nitrate-N were determined by steam distillation or

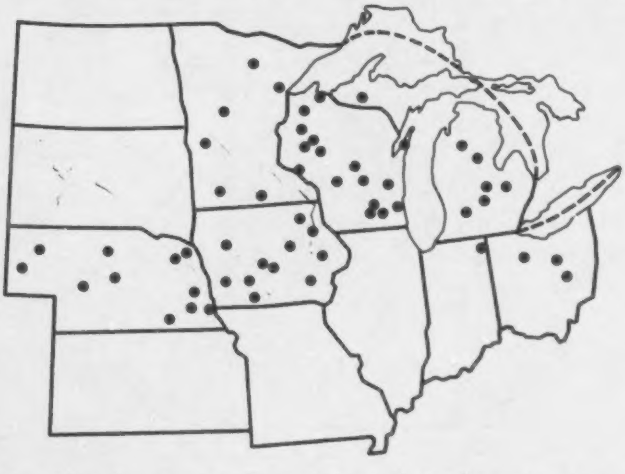

Figure 1. Location of precipitation study sites in the North Central Region.

an autoanalyzer, phosphate-P by the colorimetric method of Murphy and Riley (1962), sulfate-S by a turbidimetric procedure or by the methylene blue method of Johnson and Nishita (1952), potassium and sodium by flame photometry, and calcium and magnesium by atomic absorption spectrophotometry. These analyses were performed on particle-free precipitation samples. The major sites included in this report are shown in Fig. 1.

The data on emission of particulates, SO_x, NO_x, hydrocarbons, and carbon monoxide from various sources in each state of the study region were obtained from the National Emission Data System (NEDS) data bank in November 1979. The methods employed in calculation of the emission data for NEDS is described in the National Emission report (1976).

Table 1. Nitrogen and sulfur content of various crops[a]

Crop	Yield/Acre	Nitrogen (lb/acre)	Sulfur (lb/acre)
Corn	200 bu	320	44
Grain sorghum	8,000 lbs	260	38
Wheat	80 bu	150	22
Oats	100 bu	100	20
Rice	145 bu (6,500 lbs)	135	18
Soybeans	50 bu	185	10
Peanuts	3,000 lbs	220	25
Cotton	2.5 bale	125	23
Tobacco	2,800 lbs	95	21
Alfalfa	6 tons	335	30
Clovers	4 tons	160	18
Grasses	4 tons	120	16
Potatoes	400 bu	200	18
Cabbage	20 tons	130	37
Turnip	25 tons	114	38
Onions	20 tons	120	25

[a] Bixby and Beaton (1970).

RESULTS AND DISCUSSION

The data summarized were those available for precipitation in Iowa, Illinois, Michigan, Minnesota, Nebraska, Ohio, South Dakota, and Wisconsin. For comparison of contribution of N and S in precipitation to requirements of crops for these elements, N and S contents of various crops produced in this region are summarized in Table 1. Plant nutrient (N, P, and K) consumption in this region during 1978 is summarized in Table 2. Data on emission of particulates, SO_x, NO_x, hydrocarbon, and CO from various point and nonpoint sources in the 12 states in the region also are summarized. For convenience, the results reported will be discussed under the subheadings, pH of precipitation, each of N, S, and P in precipitation, and emission of particulates and gaseous pollutants.

pH of precipitation

Normal water in the atmosphere in equilibrium with CO_2 will have a pH of 5.7 (Barrett and Brodin, 1955), and this pH value is considered as the neutral point for atmospheric water. Limited information is available on pH of precipitation in the North Central Region. The pH values of precipitation in Iowa during 1971-1973 are summarized in Table 3. These results

Table 2. Annual plant nutrient consumption in the North Central Region (1978).[a]

State	Corn				Soybean				Wheat			
	Total area	N	P	K	Total area	N	P	K	Total area	N	P	K
	10^6 ha	------kg/ha------			10^6 ha	------kg/ha-----			10^6 ha	------kg/ha------		
Illinois	4.05	152	39	84	3.73	1	4	15	0.38	58	26	33
Indiana	2.39	145	36	87	1.66	5	11	30	0.30	55	24	42
Iowa	4.90	136	27	56	3.04	1	2	5	—	—	—	—
Kansas	0.61	127	11	13	0.58	3	1	2	4.17	36	4	1
Michigan	0.87	122	34	78	—	—	—	—	0.17	56	24	45
Minnesota	2.47	94	22	53	1.62	2	2	5	1.12	74	18	20
Missouri	0.89	131	45	58	2.23	5	6	18	0.34	57	17	38
Nebraska	2.55	154	12	7	0.51	2	3	1	1.05	22	2	—
North Dakota	—	—	—	—	—	—	—	—	3.77	21	7	1
Ohio	1.45	147	40	80	1.51	6	8	19	0.46	49	26	47
South Dakota	1.01	36	7	5	—	—	—	—	1.24	6	2	—
Wisconsin	1.01	102	34	80	—	—	—	—	—	—	—	—

[a] From Hargett and Berry (1978).

Table 3. Means of pH values of precipitation samples collected in Iowa.

Year	Ames		Boone		Charles City		Creston		Eldora		Guthrie Center	
	N[a]	pH[b]	N	pH	N	pH	N	pH	N	pH	N	pH
1971	15	6.1 ± 0.3	12	6.2 ± 0.1	11	5.9 ± 0.4	12	6.2 ± 0.4	10	6.3 ± 0.2	8	5.9 ± 0.5
1972	31	6.2 ± 0.8	33	6.3 ± 0.6	31	6.2 ± 0.5	36	6.2 ± 0.5	21	6.5 ± 0.3	33	6.2 ± 0.5
1973	26	6.0 ± 0.6	26	5.9 ± 0.7	28	6.1 ± 0.6	20	6.5 ± 0.3	18	6.3 ± 0.4	25	5.8 ± 0.8

[a] N, number of samples analyzed.

[b] Mean ± standard deviation.

Source: Tabatabai and Laflen (1976).

Table 4. Comparison of pH values of precipitation in Iowa, Illinois, Michigan, Minnesota, Nebraska, and Ohio during 1979.

State	Site	No. of samples	pH values[a]		
			Range	Average	Standard deviation
Iowa	Agronomy Farm	21	5.4-7.0	6.24	0.50
	Ames	31	4.6-6.7	6.00	0.49
	Atlantic	23	5.5-7.0	6.33	0.40
	Fairfax	17	6.3-7.2	6.78	0.31
	Sigourney	23	4.0-6.8	6.29	0.58
	Storm Lake	23	4.2-7.1	6.11	0.64
	Tripoli	25	5.2-7.1	6.35	0.48
Illinois	Bondville	26	3.9-4.9	4.29	0.19
	Dixon Springs	29	3.8-6.5	4.63	0.51
Michigan	Wellston	26	3.8-6.8	4.54	0.71
Minnesota	Lamberton	32	4.0-7.4	6.12	0.73
	Marcell	38	4.2-6.8	5.22	0.61
Nebraska	Mead	28	4.4-7.0	5.99	0.75
Ohio	Caldwell	35	3.7-5.9	4.23	0.43
	Delaware	39	3.9-6.0	4.32	0.40
	Wooster	37	3.6-6.5	4.40	0.65

[a] Precipitation in Iowa was collected on an event basis. All others were collected on a weekly basis. With the exception of the pH values for Iowa precipitation that were measured at Iowa State University, the pH values were summarized from the National Atmospheric Deposition Program data report Vol. II, Nos. 1 and 2 (1979), Natural Resource Ecology Laboratory, Colorado State Univ., Fort Collins, Colorado.

indicate that, although pH values as low as 4 have been measured for precipitation in Iowa, generally, the average pH values for six sites in Iowa is > 6.0. Analysis of the data indicates that no seasonal variation in pH values was observed (Tabatabai and Laflen, 1976). Comparison of the pH values available during 1979 for precipitation in Iowa, Illinois, Michigan, Minnesota, Nebraska, and Ohio is shown in Table 4. Generally, the average pH values of precipitation in Iowa, Nebraska, and one site (Lamberton) in Minnesota are about 6, and those of Illinois, Michigan, one site (Marcell) in Minnesota, and Ohio were between 4 and 5. The pH values of precipitation in this region are markedly different from those reported for samples from the northeastern United States and Sweden where pH values as low as 2 and 3 were measured (Likens and Bormann, 1974). With the exception of precipitation in one site (Bondville) in Illinois (Table 4), no consistently low pH values were found for precipitation in this region. It seems that SO_4-S in precipitation in the North Central Region exists as un-ionized particulate SO_4^{2-} or ionized forms neutralized by equivalent amounts of bases (e.g., $(NH_4)_2SO_4$). The data available from an extensive monitoring program in Iowa show that the occasional low pH values are not associated with high concentrations of SO_4-S and NO_3-N. Data reported by Likens and Bormann (1974) for SO_4-S concentration of rain and snow in New York indicate that present-day precipitation contains about 70% less S than precipitation preceding 1950, but it has lower pH values. From the results obtained for concentrations of SO_4-S and pH of precipitation in the North Central Region (Tables 3 and 4) and those reported by Likens and Bormann (1974) for samples in the State of New York, it seems that a factor other than SO_4-S is responsible for low pH values of some precipitation samples or that sufficient cations (e.g., NH_4^+) are not present in precipitation where acid rain is found.

The acidity of rain should not have a significant effect on the pH of agricultural soils because of the strong buffering capacity of soils relative to that of precipitation and because the acidity produced from nitrification of NH_4-forming fertilizers and other processes in soils markedly exceeds the acidity from precipitation. Recently, McFee and Kelly (1977) discussed the degree of pH shift in a typical midwestern soil (CEC = 20 meq/100 g soil) and concluded that, if the pH of precipitation were 4.0 and the annual input were 100 cm (40 in.), the reduction in soil base saturation in the plow layer (20 cm) due to acid precipitation could be 19% in 100 years. This would result in a decrease of pH by a 0.6 unit. This decrease in pH would occur only if there are no concurrent inputs of basic cations and if the exchange of H^+ was complete. But it is well known that there is input of basic ions, such as Ca^{2+} and Mg^{2+}. The acidifying effect of the H^+ ions in precipitation is lessened by accompanying neutral salts (Wiklander, 1975). On uncultivated, unfertilized soils that have low CEC, acidity in precipitation may affect the pH more than that described, but no such change in pH is expected in many years. The acidity of precipitation such as that found for rainfall in the North Central Region (Table 4) should have little or no effect on soil biological processes.

The effect of H^+ of precipitation on soils cannot be assessed because precipitation contains NH_4^+, and these ions have acidifying potential of a similar magnitude to direct H^+ inputs common in rainfall (Reuss, 1976). Therefore, the amount of acidity produced in soils, especially agricultural soils, by precipitation is insignificant in relation to the acidity produced by other causes.

Nitrogen in precipitation

Various crops require different amounts of N for optimum yield. Table 1 shows the amounts of N and S required for production of crops grown in the North Central Region. Plant nutrient (NPK) consumption in the states in this region during 1978 for production of corn, soybeans, and wheat is summarized in Table 2. Although N application varies among the states in this region, the amounts applied and those present in soils greatly exceed N input by precipitation. The information available on concentration and deposition of N in precipitation is summarized for Indiana (Tables 5-8), Iowa (Tables 9-12), Michigan (Tables 13-17), Minnesota (Tables 18-23), Nebraska (Tables 24-29), Ohio (Tables 30 and 31), South Dakota (Table 32), and Wisconsin (Tables 33-34). Although most of the information about N in precipitation is concerned with inorganic N (NH_4^+ and NO_3^-), the data from Indiana (Tables 5-8) and Wisconsin (Table 34) indicate that the concentration of organic N in precipitation often is similar to those of NH_4-N and NO_3-N.

The inorganic N added by precipitation varied among the sites even within individual states. For example, Table 10 shows that the amount of NH_4-N and NO_3-N added annually by precipitation at six sites in Iowa ranged from 9.8 kg/ha in Eldora to 14.3 kg/ha in Guthrie Center. Similar, but more striking, differences are observed for inorganic N deposition in four locations in Minnesota (Table 19), where the annual deposition of inorganic N in Morris is about half that in Lamberton. Generally, however, the amount of inorganic N added by precipitation is small compared with that mineralized from soil organic matter and that added as fertilizer. The data indicate that precipitation adds from 5 to 15 kg N/ha per year in this region, which is about 5 to 10% of the N added as fertilizer for corn production in the North Central Region. This amount of N, however, would be significant for crops that receive little or no N fertilizers.

Although the concentrations of NH_4-N and NO_3-N did not show temporal variations, generally, equal amounts of NH_4-N and NO_3-N are added by precipitation in Iowa (Table 10). More NH_4-N than NO_3-N is accumulated in Minnesota (Table 18) and Nebraska (Table 24). The results available for Iowa indicate that between 70 and 82% of the inorganic N is deposited during spring and summer (Tabatabai and Laflen, 1976). The overall average annual addition of inorganic N by precipitation in Iowa (13 kg/ha) is simi-

(text continues on page 138)

Table 5. Nitrogen and phosphorus in precipitation in Black Creek, Indiana (Site 1).

Period	Precipitation[a]	Suspended solids	Nitrogen				Phosphorus		
			NH_4^+	NO_3^-	SO[b]	SB[c]	PO_4^{3-}	SO[b]	SB[c]
	cm	mg/l	mg/l				µg/l		
1974									
June	7.98(3)	9.50	0.99	1.15	0	0	44	19	24
Nov.	8.73(1)	0	0.54	0.54	0	0	10	0	0
1975									
April	8.35(3)	106	0.42	0.65	0.32	0.18	11	19	434
May	16.86(5)	205	0.54	1.31	1.14	0.22	21	68	108
June	18.01(7)	37.9	0.27	0.60	0.13	0.09	11	61	192
July	5.54(2)	26.0	0.15	0.35	0	0.39	16	47	8
Aug.	14.68(3)	31.3	0.17	0.77	0	0.29	9	35	40
Sept.	6.74(2)	120	0.27	0.64	0	0.69	22	35	85
Oct.	4.55(2)	371	0.17	1.55	0.15	0.45	13	85	62
Nov.	7.12(2)	87.5	0.15	0.91	0.10	0.39	8	0	1,133
1976									
April	5.74(1)	5.60	0.31	0.58	0.58	0	32	0	0
May	7.45(3)	117	0.42	1.21	0.63	C.21	29	72	10
June	7.36(3)	79	0.47	1.28	0.17	0.41	31	95	47
July	7.71(3)	135	0.19	0.73	0.52	0.55	11	111	80
Aug.	3.86(2)	185	0.28	0.81	0.24	0.16	8	94	103
Sept.	6.50(1)	0.21	2.41	3.88	0	2.59	1,080	0	1,104

[a] Figure in parentheses indicates number of samples analyzed (sampled on event basis).

[b] SO, soluble organic.

[c] SB, sediment bound.

Table 6. Statistical analysis of nitrogen and phosphorus in precipitation in Black Creek, Indiana (Site 1).

Parameter[a]	Suspended solids	Nitrogen in form specified[b]				Phosphorus in form specified[b]		
		NH_4^+	NO_3^-	SO	SB	PO_4^{3-}	SO	SB
	mg/l	mg/l				µg/l		
June and Nov. (1974)								
Maximum	15.0	1.27	1.27	0	0	94	29	24
Minimum	4.0	0.54	0.54	0	0	10	9	24
Median	9.50	0.85	1.09	0	0	19	19	24
Mean	9.50	0.89	1.00	0	0	36	19	24
SD	7.78	0.30	0.32	0	0	39	14	0
No. of samples = 4								
April - Nov. (1975)								
Maximum	550	1.13	3.36	1.73	1.18	29	1,037	1,186
Minimum	4.0	0.05	0.35	0	0	3	5	0
Median	51.5	0.25	0.61	0.08	0.20	13	47	61
Mean	116	0.30	0.84	0.29	0.26	14	209	249
SD	143	0.22	0.66	0.44	0.28	8	369	422
No. of samples = 26								
April - Sept. (1976)								
Maximum	317	2.41	3.88	1.26	2.59	1,080	135	1,104
Minimum	0.21	0.16	0.21	0	0	0	0	0
Median	53.0	0.31	1.05	0.41	0.29	27	76	45
Mean	105	0.50	1.21	0.39	0.49	103	85	145
SD	108	0.60	0.94	0.37	0.72	294	40	323
No. of samples = 13								

[a] SD, standard deviation.

[b] SO, soluble organic; SB, sediment bound.

Table 7. Nitrogen and phosphorus in precipitation in Black Creek, Indiana (Site 2).

Period	Precipitation[a]	Suspended solids	Nitrogen in form specified[b]				Phosphorus in form specified[b]		
			NH_4^+	NO_3^-	SO	SB	PO_4^{3-}	SO	SB
	cm	mg/l	mg/l				µg/l		
1974									
June	7.70(2)	31.0	0.67	0.90	0	0	40	40	23
Nov.	8.00(1)	38.0	1.63	0.72	0	0	48	28	0
1975									
April	8.37(2)	14.0	0.55	1.02	0.24	0.23	14	1,004	1,108
May	15.28(6)	76.0	0.71	1.36	1.19	0.17	36	58	164
June	17.27(8)	27.4	0.44	0.73	0.17	0.62	21	85	756
July	5.56(2)	44.0	0.44	1.28	0.50	1.18	63	39	54
Aug.	16.57(3)	29.3	0.23	0.85	0	0.51	60	39	54
Sept.	7.53(2)	5.0	0.32	0.52	0	0.66	9	35	8
Oct.	5.00(1)	55.0	0.35	1.48	0	0.45	0	0	0
Nov.	7.31(2)	74.5	0.25	0.84	0.04	0.15	1	0	1,156
1976									
April	7.01(1)	8.0	0.79	1.09	0.24	0.15	0	56	68
May	6.24(3)	97.0	0.77	2.01	0.33	0.08	28	99	0
June	6.43(3)	23.5	0.39	0.78	0.18	0.71	49	86	14
July	8.07(3)	42.3	0.35	0.51	0.79	0.86	83	151	90
Aug.	3.68(2)	68.5	0.44	0.81	0	0.68	43	139	84
Sept.	6.27(1)	394	0.37	2.25	0	2.83	63	46	383

[a] Figure in parentheses indicates number of samples analyzed (sampled on event basis).

[b] SO, soluble organic; SB, sediment bound.

Table 8. Statistical analysis of nitrogen and phosphorus in precipitation in Black Creek, Indiana (Site 2).

Parameter[a]	Suspended solids	Nitrogen in form specified[b]				Phosphorus in form specified[b]		
		NH_4^+	NO_3^-	SO	SB	PO_4^{3-}	SO	SB
	mg/l	mg/l				µg/l		
			June and Nov. (1974)					
Maximum	38.0	1.63	1.27	0	0	48	68	23
Minimum	31.0	0.54	0.54	0	0	32	13	0
Median	34.5	0.99	0.84	0	0	43	36	11
Mean	34.5	0.81	0.72	0	0	48	28	11
SD	4.55	0.57	0.38	0	0	9	28	16
No. of samples = 3								
			April - Nov. (1975)					
Maximum	258	1.42	4.56	1.52	2.13	107	1,048	1,186
Minimum	2.0	0.05	0.31	0	0	1	11	0
Median	43.2	0.45	0.97	0.36	0.49	30	227	420
Mean	20.0	0.38	0.68	0.09	0.38	17	46	92
SD	53.8	0.30	0.90	0.49	0.51	30	385	511
No. of samples = 26								
			April - Sept. (1976)					
Maximum	395	1.31	3.46	0.99	2.83	129	190	383
Minimum	2.0	0.26	0.16	0	0	0	46	0
Median	83.7	0.51	1.17	0.33	0.78	49	107	83
Mean	46.0	0.42	1.05	0.30	0.65	30	89	51
SD	116	0.30	0.89	0.35	0.83	39	50	115
No. of samples = 13								

[a] SD, standard deviation

[b] SO, soluble organic; SB, sediment bound

Table 9. Average monthly addition by precipitation of ammonium N, nitrate-N, and sulfate-S at six sites in Iowa.[a]

Site	Nutrient	Month												Average
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
		kg/ha												kg/ha/month
Ames	NH_4-N	0.4	0.1	0.6	0.7	0.7	0.5	0.7	0.5	0.6	0.6	0.5	0.1	0.5
	NO_3-N	0.2	0.1	0.6	0.6	0.7	0.6	1.0	0.6	0.7	0.7	0.5	0.1	0.5
	SO_4-S	0.7	0.8	2.0	2.2	2.0	1.4	1.8	1.4	1.1	1.7	1.2	0.2	1.4
Boone	NH_4-N	0.1	0.4	0.5	0.5	1.0	0.4	0.6	0.6	0.6	0.4	0.3	0.2	0.5
	NO_3-N	0.1	0.2	0.8	0.5	1.1	0.8	0.9	0.6	0.6	0.6	0.6	0.1	0.6
	SO_4-S	0.8	0.6	2.1	1.7	2.0	1.1	1.3	1.3	0.9	1.5	1.6	0.3	1.3
Charles City	NH_4-N	0.1	0.1	1.3	0.7	0.8	1.0	0.8	0.3	0.7	0.7	0.1	0.3	0.6
	NO_3-N	0.1	0.1	0.5	0.7	0.5	0.6	0.6	0.3	0.7	0.7	0.4	0.2	0.5
	SO_4-S	0.3	0.4	2.2	1.5	1.2	0.8	1.3	0.7	1.8	1.5	0.8	0.7	1.1
Creston	NH_4-N	—	0.8	0.3	0.6	1.0	0.5	1.1	0.6	0.9	0.5	0.2	—	0.7
	NO_3-N	—	0.7	0.2	1.0	0.7	0.4	0.5	0.5	0.8	0.5	0.5	—	0.6
	SO_4-S	—	1.2	1.5	3.1	1.8	0.5	1.5	2.1	1.6	1.7	1.7	—	1.7
Eldora	NH_4-N	—	—	—	0.5	1.1	1.0	0.5	0.3	0.6	0.5	0.1	—	0.6
	NO_3-N	—	—	—	0.5	0.9	0.7	0.5	0.5	0.4	0.5	0.1	—	0.5
	SO_4-S	—	—	—	3.1	2.1	1.9	1.5	2.2	0.9	1.6	1.4	—	1.8
Guthrie Center	NO_4-N	0.1	0.1	1.0	0.8	0.9	1.0	0.8	0.4	0.5	0.4	0.8	—	0.6
	NO_3-N	0.1	0.1	0.8	0.7	0.7	1.0	0.8	0.5	0.1	0.7	1.1	—	0.6
	SO_4-S	0.6	0.6	2.2	2.6	1.4	1.6	1.9	1.2	0.8	1.2	1.7	—	1.4

[a] September 1971 - December 1973.

Table 10. Amounts of ammonium-N, nitrate-N, and sulfate-S added annually by precipitation at six sites in Iowa.

Site	NH_4-N	NO_3-N	SO_4-S
	kg/ha/year[a]		
Ames	6.0	6.0	16.8
Boone	6.0	7.2	15.6
Charles City	7.2	6.0	13.2
Creston	6.7	6.0	16.7
Eldora	5.0	4.8	17.3
Guthrie Center	7.1	7.2	16.1
Average	6.3	6.2	16.0

[a] The values obtained for Creston, Eldora, and Guthrie Center were calculated from average annual nutrient concentration and percentage of the annual precipitation received during sampling period.

Source: Tabatabai and Laflen (1976).

Table 11. Ammonium- and nitrate-N in precipitation in Treynor, Iowa (Site 1).

Month	Year	Amt. of precip.	No. of events[a]	Precip. sampled	NH_4-N			NO_3-N		
					Range	Mean	Total	Range	Mean	Total
		cm		cm	mg/l	mg/l	kg/ha	mg/l	mg/l	kg/ha
Jan.	1971	1.35	2(0)	0	—	—	—	—	—	—
	1972	0.40	2(0)	0	—	—	—	—	—	—
	1973	3.48	6(6)	3.48	0.14-1.25	0.48	0.17	0.19-0.40	0.32	0.11
Feb.	1971	2.97	6(0)	0	—	—	—	—	—	—
	1972	0.69	3(0)	0	—	—	—	—	—	—
	1973	2.72	3(2)	2.05	0.44-1.26	0.55	0.15	0.65-0.97	0.65	0.18
March	1971	0.76	5(0)	0	—	—	—	—	—	—
	1972	1.42	7(1)	4.1	—	—	—	—	—	—
	1973	13.7	12(11)	13.6	0.22-1.91	0.49	0.66	0.27-0.64	0.40	0.54
April	1971	2.18	4(1)	0.93	—	0.37	0.08	—	0.10	0.02
	1972	12.3	9(8)	11.2	0.12-0.60	0.26	0.33	0.15-1.21	0.43	0.53
	1973	9.53	10(6)	7.80	0.22-1.38	0.79	0.75	0.05-0.75	0.27	0.26
May	1971	22.5	13(5)	19.6	0.23-1.00	0.60	1.34	0.18-0.94	0.55	1.22
	1972	14.6	11(8)	12.3	0.14-0.83	0.55	0.80	0.18-0.90	0.47	0.68
	1973	12.8	10(6)	11.2	0.36-2.62	0.64	0.82	0.11-1.11	0.23	0.29
June	1971	10.5	8(2)	6.78	0.19-0.55	0.29	0.30	0.11-0.39	0.19	0.20
	1972	2.51	5(3)	1.60	0.13-0.86	0.49	0.12	0.32-0.36	0.36	0.09
	1973	4.0	6(4)	3.53	0.25-1.68	1.11	0.44	0.16-0.89	0.51	0.20
July	1971	4.56	6(2)	3.48	0.19-0.44	0.30	0.13	0.38-0.61	0.51	0.24
	1972	12.0	12(6)	9.67	0.11-0.64	0.20	0.24	0.21-1.21	0.29	0.35
	1973	15.1	9(8)	14.9	0.26-0.99	0.51	0.76	0.47-1.57	0.97	1.47
Aug.	1971	3.12	5(2)	1.85	—	0.55	0.17	0.47-1.03	0.74	0.24
	1972	4.08	9(3)	2.90	0.50-0.68	0.60	0.25	0.35-0.94	0.49	0.20
	1973	8.41	5(4)	8.26	0.39-7.16	0.79	0.66	0.53-0.76	0.54	0.46
Sept.	1971	1.17	5(0)	0	—	—	—	—	—	—
	1972	17.7	12(11)	16.9	0.13-0.83	0.43	0.76	0.13-0.77	0.31	0.55
	1973	20.7	15(13)	20.5	0.20-2.26	0.80	1.66	0.12-1.47	0.42	0.87
Oct.	1971	12.1	9(3)	8.36	0.19-0.33	0.23	0.28	0.05-0.19	0.12	0.16
	1972	10.2	7(6)	10.1	0.10-0.54	0.18	0.18	0.09-0.60	0.11	0.11
	1973	7.54	3(3)	7.54	0.28-1.38	0.33	0.25	0.16-0.63	0.18	0.13
Nov.	1971	10.2	7(4)	9.30	0.13-0.41	0.25	0.26	0.15-0.42	0.16	0.17
	1972	6.60	7(7)	6.60	0.08-1.04	0.61	0.40	0.31-0.56	0.46	0.30
	1973	3.38	5(4)	3.33	0.07-2.14	0.30	0.10	0.55-9.66	2.73	0.92
Dec.	1971	2.36	6(1)	1.47	—	0.36	0.09	—	0.39	0.09
	1972	3.68	5(5)	3.68	0.31-0.44	0.30	0.11	0.25-0.40	0.33	0.12
	1973	4.67	6(6)	4.67	0.37-2.14	0.98	0.46	0.47-9.66	4.03	1.88
Total	1971	73.8	76(20)	51.8	0.13-1.00	0.39	2.71	0.05-1.03	0.34	2.37
	1972	86.2	89(58)	75.4	0.08-0.83	0.38	3.27	0.09-1.21	0.35	3.04
	1973	106.0	90(73)	100.9	0.07-7.16	0.65	6.87	0.05-9.66	0.69	7.32

[a] Figure in parentheses is number of samples analyzed.

Table 12. Ammonium- and nitrate-N in precipitation in Treynor, Iowa (Site 2).

Month	Year	Amt. of precip.	No. of events[a]	Precip. sampled	NH_4-N			NO_3-N		
					Range	Mean	Total	Range	Mean	Total
		cm		cm	mg/1	mg/1	kg/ha	mg/1	mg/1	kg/ha
Jan.	1971	1.35	2(0)	0	--	--	--	--	--	--
	1972	0.41	2(0)	0	--	--	--	--	--	--
	1973	3.48	6(6)	3.48	0.21-0.62	0.32	0.11	0.20-1.61	0.61	0.21
Feb.	1971	2.97	6(0)	0	--	--	--	--	--	--
	1972	0.69	3(0)	0	--	--	--	--	--	--
	1973	2.82	4(2)	2.06	0.45-1.32	0.55	0.16	0.53-0.72	0.60	0.17
March	1971	0.76	5(0)	0	--	--	--	--	--	--
	1972	1.42	7(0)	0	--	--	--	--	--	--
	1973	13.67	12(11)	13.6	0.28-1.41	0.46	0.63	0.32-0.92	0.41	0.56
April	1971	2.08	4(1)	1.04	--	0.37	0.08	--	0.10	0.02
	1972	12.1	9(8)	10.9	0.24-1.04	0.40	0.48	0.14-1.05	0.35	0.43
	1973	8.99	10(6)	7.24	0.44-1.43	1.05	0.94	0.24-0.55	0.45	0.40
May	1971	22.2	13(5)	19.1	0.40-0.90	0.62	1.38	0.24-1.10	0.46	1.03
	1972	14.5	11(8)	13.5	0.19-0.77	0.57	0.83	0.20-1.02	0.52	0.75
	1973	12.5	10(7)	11.4	0.56-2.13	0.77	0.96	0.32-0.53	0.34	0.43
June	1971	10.36	8(2)	6.50	0.27-0.40	0.31	0.31	0.10-0.82	0.30	0.31
	1972	2.44	5(3)	1.65	0.20-0.50	0.32	0.08	0.37-0.74	0.37	0.09
	1973	3.78	6(3)	2.90	0.24-0.60	0.46	0.18	0.15-0.57	0.43	0.16
July	1971	4.29	6(2)	3.32	0.27-0.27	0.27	0.11	0.11-0.39	0.22	0.10
	1972	11.6	12(7)	9.55	0.12-0.73	0.21	0.25	0.17-1.34	0.34	0.39
	1973	14.8	9(6)	13.7	1.73-2.35	1.99	2.95	0.76-1.57	1.22	1.80
Aug.	1971	3.68	5(2)	2.24	0.55-0.55	0.55	0.20	0.47-0.70	0.56	0.20
	1972	4.19	9(5)	3.02	0.41-0.78	0.59	0.25	0.38-1.17	0.54	0.22
	1973	7.92	5(3)	6.43	0.53-0.55	0.54	0.43	0.38-0.75	0.42	0.34
Sept.	1971	1.30	5(0)	0	--	--	--	--	--	--
	1972	18.6	12(8)	17.8	0.20-0.77	0.37	0.70	0.16-0.72	0.31	0.58
	1973	20.8	15(13)	20.7	0.28-1.08	1.77	1.60	0.28-0.76	0.35	0.72
Oct.	1971	12.5	9(3)	8.64	0.19-0.24	0.22	0.28	0.05-0.30	0.16	0.20
	1972	10.2	7(3)	9.09	0.19-0.30	0.22	0.22	0.17-0.21	0.13	0.13
	1973	7.72	3(3)	7.72	0.20-0.90	0.22	0.17	0.15-0.60	0.17	0.13
Nov.	1971	10.3	7(4)	9.45	0.05-0.28	0.21	0.21	0.10-0.26	0.17	0.17
	1972	6.60	7(7)	6.60	0.16-1.32	0.39	0.26	0.23-0.63	0.44	0.29
	1973	3.38	5(4)	3.33	0.57-1.10	0.64	0.21	0.46-6.02	2.39	0.81
Dec.	1971	2.36	6(1)	1.47	--	0.36	0.09	--	0.39	0.09
	1972	3.68	5(5)	3.68	0.08-0.79	0.30	0.11	0.23-0.67	0.46	0.17
	1973	4.67	6(6)	4.67	0.29-1.10	0.60	0.28	0.71-6.02	2.88	1.35
Total	1971	74.1	76(20)	51.8	0.05-0.90	0.39	2.71	0.05-1.10	0.32	2.17
	1972	86.5	89(54)	75.9	0.08-1.32	0.38	3.26	0.14-1.34	0.36	3.15
	1973	104.6	91(70)	97.1	0.20-2.35	0.82	8.62	0.15-6.02	0.68	7.07

[a] Figure in parentheses is number of samples analyzed.

Table 13. Monthly contribution of total phosphorus, inorganic nitrogen, and organic nitrogen from precipitation to Houghton Lake, Roscommon County, Michigan, during 1972.[a]

Month	Total P	Inorganic N	Organic N
	g/ha/month	kg/ha/month	
Jan.	0.555	0.060	0.045
Feb.	0.555	0.097	0.067
March	2.465	0.193	0.134
Apr.	6.767	0.240	0.168
May	43.42	0.347	0.241
June	14.72	0.431	0,302
July	14.83	0.508	0.353
Aug.	45.61	1.080	0.756
Sept.	25.13	0.557	0.392
Oct.	22.33	0.495	0.347
Nov.	5.263	0.188	0.129
Dec.	2.576	0.268	0.190
Total	184.2	4.464	3.124

[a] Surface area of lake = 31.3 square miles (8,113 hectares).

Source: Pecor et al. (1973).

Table 14. Average daily nutrient concentrations in precipitation collected at two stations near Houghton Lake, Roscommon County, Michigan during 1972.

Date	Precipitation Type	Total P	Total Soluble P	PO_4-P	NO_2-N	NO_3-N	NH_4-N
		µg/l				mg/l	
2-9	Snow	4	---	1	1	0.26	0.02
2-27	"	0	0	0	Tr	0.40	0.02
4-2	Rain	40	---	14	6	0.52	0.13
4-9	Snow	5	---	3	Tr	0.22	0.02
4-30	Rain[a]	17	---	7	Tr	1.06	0.29[b]
5-1	"	106	---	56	Tr	0.92	0.29[b]
5-4	"	16	---	14	2	0.13	0.40
5-5	"	29	---	14	1	0.24	0.27
5-8	"	101	91	79	2	0.33	0.24
5-9	"	14	11	11	Tr	0.36	0.17
5-10	"	42	33	21	3	0.50	0.49
5-11	"	35	28	27	3	0.22	0.36
5-26	"	255	239	229	2	0.57	0.64
5-28	"	173	159	127	2	0.45	0.23
5-29	"[a]	150	136	101	3	0.23	0.32
6-1	"[a]	42	38	31	3	1.15	0.84
6-4	"[a]	28	14	14	Tr	0.65	0.29
6-5	"[a]	42	42	21	1	0.35	0.26
6-8	"[a]	63	63	42	3	0.34	0.39
6-12	"[a]	14	14	7	3	0.35	0.19
6-27	"	15	11	9	3	0.55	0.61
6-28	"	11	7	1	2	0.26	0.17
6-29	"[a]	12	7	Tr	2	0.10	0.06
7-1	"	14	16	3	18	0.18	0.80
7-2	"	14	7	3	3	0.58	0.40
7-12	"	56	50	45	Tr	0.19	0.29
7-26	"	12	9	5	1	0.34	0.16
7-30	"	14	11	7	3	0.46	0.22
7-31	"[a]	11	7	7	3	0.28	0.18
8-1	"	14	14	7	1	0.36	0.34
8-2	"	16	7	7	0	0.25	0.26
8-8	"[a]	28	7	3	0	0.53	0.11
8-9	"	26	7	9	2	0.45	0.25
8-20	"	85	85	61	3	0.77	0.41
8-31	"	39	39	29	1	0.58	0.52
9-6	"	27	16	12	2	0.61	0.12
9-17	"	15	13	9	Tr	0.21	0.07
9-18	"	14	14	9	Tr	0.31	0.09
9-21	"[a]	84	84	77	3	0.69	0.51
9-26	"	23	---	13	3	0.86	0.20
Average		43	40	28	2	0.44	0.29

[a] Precipitation occurred at only one station.

[b] Estimated using mean NH_4-N concentration for the sampling period.

Source: Pecor et al. (1973).

Table 15. Average monthly total phosphorus and inorganic nitrogen concentrations in precipitation at Houghton Lake, Roscommon County, Michigan, during 1972.

Month	Precipitation Type	Total P	Inorganic N
		mg/l	mg/l
January	Snow	0.003[a]	0.314[a]
February	Snow	0.002	0.353
March	Snow	0.003[a]	0.314[a]
April	Rain & Snow	0.021	0.744
May	Rain	0.092	0.735
June	Rain	0.028	0.819
July	Rain	0.020	0.685
August	Rain	0.034	0.806
September	Rain	0.033	0.732
October	Rain	0.033[a]	0.732[b]
November	Rain & Snow	0.021[c]	0.744[c]
December	Snow	0.003[a]	0.314[a]
Annual Average		0.027	0.608

[a] Estimated from mean of all snow samples

[b] Estimated from September mean

[c] Estimated from April mean

Source: Pecor et al. (1973).

Table 16. Amounts of sulfate-S added annually by rain water at five sites in Michigan.

County	Sulfur added (kg/ha/yr) during the period indicated[a]	
	1959-60	1960-61
Kalamazoo	12.8	14.2
Ingham	13.3	14.7
Clinton	10.2	10.4
Saginaw	10.2	9.8
Antrim	8.3	9.6
Average	11.0	11.7

[a] 1959-60 is April 1, 1959 - March 31, 1960.
1960-61 is April 1, 1960 - March 31, 1961.

Source: Cressman and Davis (1962).

Table 17. Concentration and deposition of some nutrients in precipitation in Ottawa National Forest, Michigan[a], Sylvania Tract.

Parameter	Average concentration			Average deposition		
	Rain	Snow	Vol. Wtd. Avg.	Rain	Snow	Annual
	mg/l			kg/ha/yr		
Total P	0.068	0.027	0.060	0.42	0.04	0.46
Total N	1.47	0.61	1.30	9.2	0.9	10.1
Ca[b]	—	—	0.46	—	—	3.6
Mg[b]	—	—	0.13	—	—	1.0
SO_4^{2-}	3.6	1.3	3.2	22.3	1.9	24.4
	units					
pH	5.4	5.6	5.4	—	—	—
	µmhos					
Conductivity at 25°C	24	17	23	—	—	—

[a] 62.5 cm of rain and 15.0 cm of snow (77.5 cm total annual precipitation).

[b] Average of results obtained in 1972-1975.

Table 18. Nitrogen and phosphorus in precipitation in Morris, Minnesota.

Period	Precip.	No. of events	Events sampled	Precip. sampled	Nitrogen in precipitation						Phosphorus in precipitation		
					NH_4-N			NO_3-N					
					Range	Mean	Total	Range	Mean	Total	Range	Mean	Total
	cm			cm	mg/l		kg/ha	mg/l		kg/ha	µg/l		g/ha
1972													
Apr.	6.6	11	5	6.2	0.42-0.68	0.51	0.35	0.10-0.28	0.21	0.16	0-6	2	0.5
May	11.2	13	10	10.9	0.70-1.97	1.37	1.70	0.42-0.74	0.64	0.71	5-148	44	90.4
June	5.6	5	5	5.6	0.81-1.02	0.92	0.47	0.32-0.53	0.42	0.19	6-140	73	11.9
July	16.0	14	5	15.0	0.46-2.74	1.09	2.06	0.21-0.60	0.38	0.63	0-65	16	35.9
Aug.	4.4	9	3	2.3	0.21-0.38	0.30	0.10	0.32-0.35	0.34	0.15	0-14	7	2.5
Sept.	1.0	5	2	0.4	—	1.9	0.18	—	0.91	0.09	—	0	0
Oct.	5.6	7	5	3.3	0.38-1.09	0.74	0.25	0.32-1.51	0.92	0.28	0-6	3	0.7
Nov.	3.6	7	1	3.3	—	0.21	0.08	—	0.38	0.13	—	12	0.4
Dec.	6.5	11	2	1.0	—	2.32	0.39	—	0.28	0.12	—	10	0.4
1973													
Jan.	0.4	5	2	0.3	—	0.34	0.02	—	0.56	0.02	—	0	0
Feb.	1.2	4	2	1.1	—	0.21	0.02	—	0.78	0.09	—	0	0
Mar.	4.6	9	6	3.1	0.39-1.45	0.94	0.31	0.16-0.89	0.55	0.18	6-12	9	3.5
Apr.	2.8	5	3	2.6	0.57-2.37	1.68	0.48	0.23-0.75	0.57	0.17	11-30	20	5.5
May	9.7	11	7	9.3	0.15-1.23	0.71	0.39	0.07-0.30	0.18	0.12	5-103	30	16.8
June	2.5	8	3	1.0	—	2.25	0.31	—	2.20	0.30	—	30	0.5
July	14.1	10	7	13.7	0.40-2.07	0.93	1.23	0.14-1.11	0.43	0.59	2-190	41	53.0
Aug.	4.5	15	10	4.0	0.55-2.37	1.27	0.48	0.12-1.31	0.63	0.22	6-35	16	3.4
Sept.	5.7	9	6	5.4	0.32-4.82	1.41	0.53	0.10-2.84	0.75	0.24	2-15	8	3.4
Oct.	4.5	4	2	4.4	0.30-0.47	0.38	0.20	0.14-0.16	0.15	0.07	—	3	1.3
Nov.	2.4	3	3	2.4	0.91-2.73	1.66	0.31	0.36-1.39	0.80	0.11	7-26	14	2.0
Dec.	1.6	11	6	1.4	0.22-0.83	0.42	0.07	0.60-1.28	0.96	0.15	18-30	22	3.6
1974													
Jan.	0.1	1	1	0.1	—	1.24	<0.1	—	0.42	<.01	—	12	0
Feb.	1.7	7	6	1.7	0.17-2.19	0.64	0.12	0.15-2.40	0.64	0.12	5-18	11	1.3
Mar.	1.2	8	5	0.9	0.38-1.61	0.71	0.09	0.08-0.91	0.35	0.04	8-50	32	1.3

Table 19. Nitrogen accumulation in precipitation at four Minnesota locations during sampling periods in 1975-1978.

Location	Long term avg. precip.	Year	Year's total precip.	Sampling period	No. precip. events	Precip. during sampling period	NH_4-N-		NO_3-N		Total N accumulation during sampling period		
							Conc.[a]	Accum.	Conc.[a]	Accum.			
	cm		cm			cm	mg/1	kg/ha	mg/1	kg/ha	kg/ha	kg/ha-cm	cm. precip/kg
Waseca	76.1	1975	72.9	5/9 -11/20	31	34.2	0.98	2.13	1.08	2.47	5.60	0.16	6.3
		1976	44.3	3/29-10/19	39	35.4	1.49	3.81	1.06	2.68	6.49	0.18	5.6
		1977	104.5	4/1 -10/1	57	71.6	1.33	6.70	1.10	4.88	11.58	0.16	5.6
		1978	78.4	4/2 -11/13	71	62.4	0.97	4.17	0.83	3.35	7.50	0.12	8.3
	4-Yr	Avg.									7.73		
Lamberton	63.5	1975	59.3	5/7 - 9/11	17	17.2	2.07	2.33	1.71	1.58	3.91	0.22	4.5
		1976	31.7	5/28- 9/26	12	15.4	2.13	3.28	2.95	2.91	6.20	0.40	2.5
		1977	86.2	3/29-10/8	40	53.2	1.49	6.34	1.12	3.74	10.09	0.19	5.6
		1978	51.7	4/18-11/13	38	36.4	1.59	3.70	1.54	4.39	8.09	0.22	4.5
	4-Yr	Avg.									7.07		
Morris	60.4	1976	25.1	4/16- 8/26	12	10.6	1.51	1.01	0.84	0.58	1.59	0.15	6.7
		1977	86.6	4/3 -11/9	40	58.1	0.65	3.22	0.51	2.30	5.52	0.10	10.0
		1978	56.0	4/2 -11/13	47	47.8	0.89	2.50	0.60	2.22	4.72	0.10	10.0
	3-Yr	Avg.									3.95		
Staples	68.3	1977	78.2	5/15-10/8	39	47.0	0.66	2.79	0.84	2.59	5.38	0.11	9.1
		1978	43.8[b]	4/23-11/14	32	37.1	0.50	1.66	0.43	1.37	3.03	0.08	12.5
	2-Yr	Avg.									4.20		

[a] Concentration is not adjusted for precipitation amount but is simply an average overall precipitation event.

[b] April through November.

Table 20. Estimated yearly nitrogen accumulation at four Minnesota locations during 1975-1978.

Location	Year	Sampling period precipitation as a % of year's total	Annual N[a] accumulation
			kg/ha
Waseca	1975	46.8	9.9
	1976	79.9	8.1
	1977	68.5	16.9
	1978	79.5	9.4
	Avg.		11.1
Lamberton	1975	29.1	13.5
	1976	48.7	12.8
	1977	61.7	16.4
	1978	70.4	11.5
	Avg.		13.6
Morris	1976	42.2	3.8
	1977	67.1	8.2
	1978	85.3	5.5
	Avg.		5.8
Staples	1977	60.1[b]	9.0
	1978	84.7	3.6

[a] Extrapolated from data in Table 18.

[b] April through November precipitation.

Table 21. Sulfate and pH of precipitation samples from Marcell Experimental Forest, Minnesota[a] (data from NC-141 site).

Parameter	Average concentration			Average deposition		
	Rain	Snow	Vol. Wtd. Avg.	Rain	Snow	Annual
	mg/l			kg/ha/yr		
SO_4^{2-}[b]	2.35	1.60	2.20	14.7	2.4	17.1
	units					
pH[c]	4.6	4.1	4.5	—	—	—
	µmhos					
Conductivity at 25°C	12	11	12	—	—	—

[a] 62.5 cm of rain and 15.0 cm of snow (77.5 cm total annual precipitation).

[b] 32 rain samples, 19 snow samples, 1978-79.

[c] 35 rain samples, 19 snow samples, 1978-79.

Table 22. Chemical composition of precipitation in Cloquet Forestry Center, Minnesota.[a]

Parameter	pH	Average concentration[b]	Average annual deposition
		mg/l	kg/ha/yr
Total P		0.036	0.22
Total N		0.79	4.94
K		0.54	3.38
Ca		1.67	10.44
Mg		0.23	1.44
SO_4^{2-}[b]		1.06	6.44
pH[b]	5.4		

[a] 10 samples during 1975, 62.5 cm of rain and 15.0 cm of snow (77.5 cm total precipitation).

[b] SO_4^{2-} and pH data are from 25 samples in 1977 at the same site as the 1975 data.

Table 23. Chemical composition of precipitation in Marcell Experimental Forest, Minnesota[a].

Parameter	Average concentration[b]			Average deposition		
	Rain	Snow	Vol. Wtd Avg.	Rain	Snow	Annual
	mg/l			kg/ha/yr		
Total P	0.059	0.063	0.060	0.39	0.10	0.49
Sol. P	0.010	0.006	0.009	0.06	0.01	0.07
Total N	0.72	0.36	0.65	4.52	0.55	5.07
NH_4-N	0.40	0.18	0.36	2.48	0.27	2.75
NO_3-N	0.28	0.35	0.29	1.72	0.53	2.25
K	0.16	0.04	0.14	0.99	0.06	1.05
Na	0.15	0.12	0.14	0.92	0.17	1.09
Ca	0.48	0.33	0.45	2.98	0.50	3.48
Mg	0.10	0.07	0.09	0.60	0.10	0.70

[a] 62.5 cm of rain and 15.0 cm of snow (77.5 cm average total annual precipitation).

[b] 6 snow samples and 45 rain samples during 1971, 1972, and 1973.

Table 24. Chemical composition of precipitation in Nebraska.

Location	Annual precip.	No. of samples[a]	Avg. yearly concentration and deposition			
			NH_4-N	NO_3-N	PO_4-P	SO_4-S
	cm		mg/l[b]			
Northeast						
Concord	38	24	2.33(13.7)	1.00(5.8)	0.20(1.2)	—
Pierce	58	8	—	—	—	—(4.6)
Northcentral						
Valentine	46	8	—	—	—	—(4.6)
Halsey	46	8	—	—	—	—(7.3)
Southcentral						
Clay Center	58	9	0.84(4.9)	0.61(3.6)	0.10(0.6)	—
Red Cloud	38	8	—	—	—	—(6.1)
Southwest						
North Platte	46	19	0.95(4.4)	0.71(3.3)	0.03(0.1)	—
Southeast						
Lincoln	69	8	—	—	—	—(9.2)
Auburn	76	8	—	—	—	—(13.1)
Western						
Scotts Bluff	41	14	0.96(3.9)	0.44(1.8)	0.10(0.4)	—
Alliance	41	8	—	—	—	—(5.7)
East						
Mead	30	26	1.16(8.0)	0.76(3.2)	0.05(0.4)	—

[a] Rainfall was collected continuously; submitted for analysis monthly during 1970-72 for N and P; SO_4-S = analysis quarterly on samples collected during 1959-60.

[b] Figures in parentheses = kg/ha/year.

Table 25. Nitrogen and phosphorus in precipitation samples from Scottsbluff, Nebraska.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					1970							
Precip. (cm)	—	—	—	—	—	—	—	—	0.91	—	—	0.58
NH_4-N (mg/l)	—	—	—	—	—	—	—	—	1.02	—	—	0.42
NO_3-N (mg/l)	—	—	—	—	—	—	—	—	0.64	—	—	0.42
PO_4-P (mg/l)	—	—	—	—	—	—	—	—	0.13	—	—	0.20
					1971							
Precip. (cm)	0.28	1.12	3.33	4.34	12.01	6.27	5.44	—	5.31	—	—	—
NH_4-N (mg/l)	0.64	2.09	1.19	0.42	0.60	0.45	—	—	0.63	—	—	—
NO_3-N (mg/l)	0.42	1.43	0.45	0.29	0.25	0.30	—	—	0.31	—	—	—
PO_4-P (mg/l)	0.20	0.20	0.36	0.02	0.02	Tr	—	—	0.05	—	—	—
					1972							
Precip. (cm)	—	—	—	6.68	4.95	12.42	8.64	4.65	4.52	0.56	2.06	—
NH_4-N (mg/l)	—	—	—	1.31	0.35	0.53	1.55	0.32	1.58	0.50	0.44	—
NH_3-N (mg/l)	—	—	—	0.71	0.13	0.25	0.32	0.12	0.50	0.53	0.64	—
PO_4-P (mg/l)	—	—	—	0.08	0.04	0.02	0.17	0.01	0.02	0.23	0.37	—
					1973							
Precip. (cm)	—	—	4.67	4.37	2.46	2.62	8.76	0.43	10.72	0.64	—	—
NH_4-N (mg/l)	—	—	1.81	1.02	0.82	2.63	0.41	1.81	0.12	0.18	0.23	1.66
NO_3-N (mg/l)	—	—	1.40	0.61	0.56	0.61	0.47	1.17	0.76	0.29	0.56	1.01
PO_4-P (mg/l)	—	—	0.02	0.01	0.10	0.73	0.03	0.42	0.03	0.04	0.10	0.07

Table 26. Nitrogen and phosphorus in precipitation samples from North Platte, Nebraska.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970												
Precip. (cm)	—	—	—	—	—	—	—	—	4.60	2.87	2.16	0.46
NH_4-N (mg/l)	—	—	—	—	—	—	—	—	0.63	0.41	0.29	1.43
NO_3-N (mg/l)	—	—	—	—	—	—	—	—	0	1.10	1.29	1.00
PO_4-P (mg/l)	—	—	—	—	—	—	—	—	0.16	0.01	0	0
1971												
Precip. (cm)	1.19	—	2.46	4.90	6.45	14.83	8.84	—	5.11	4.45	2.34	—
NH_4-N (mg/l)	0.50		0.37	—	0.98	0.83	1.56	—	0.38	0.38	1.13	—
NH_3-N (mg/l)	1.14	—	0.42	—	0.98	0.40	0.93	—	0.50	0.76	0.76	—
PO_4-P (mg/l)	0	—	0.03	0.04	0.07	0.05	0.01	—	Tr	0.03	Tr	—
1972												
Precip. (cm)	—	—	1.93	2.84	10.98	7.16	15.60	2.06	2.29	2.16	—	—
NH_4-N (mg/l)	—	—	1.21	1.18	0.71	1.34	—	1.64	1.23	1.93	—	—
NH_3-N (mg/l)	—	—	0.83	0.76	0.43	0.73	0.63	0.88	0.31	0.38	—	—
PO_4-P (mg/l)	—	—	0.03	0.03	0.01	0.01	0.04	0.04	—	—	—	—
1973												
Precip. (cm)	0.99	—	6.30	3.99	10.92	3.05	7.49	1.63	12.75	3.43	—	—
NH_4-N (mg/l)	1.20	—	0.73	1.23	2.22	3.77	1.61	0.80	0.64	0	—	—
NO_3-N (mg/l)	2.46	—	0.94	0.91	0.38	0.50	0.64	1.02	0.15	0.12	—	—
PO_4-P (mg/l)	0.01	—	0.02	0	0.48	0.68	0.22	0.03	0	0.12	—	—

Table 27. Nitrogen and phosphorus in precipitation samples from Clay Center, Nebraska.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1972												
Precip. (cm)	--	--	--	--	19.81	11.07	16.97	6.63	6.07	3.10	9.07	2.03
No. of events	--	--	--	--	13	6	10	5	5	6	9	4
NH_4-N (mg/l)	--	--	--	--	0.43	1.06	0.70	0.56	0.94	0.79	0.85	1.20
NO_3-N (mg/l)	--	--	--	--	0.30	0.91	0.58	0.41	0.35	0.53	0.56	0.82
PO_4-P (mg/l)	--	--	--	--	0.08	0.33	0.14	0.02	0.20	0.04	0.01	0
1973												
Precip. (cm)	1.65	0.86	16.51	8.18	12.88	1.96	13.67	2.87	26.75	8.94	4.98	5.28
No. of events	3	4	12	9	8	7	7	5	14	2	2	7
NH_4-N (mg/l)	0.61	1.72	1.58	1.02	0.94	0.91	1.64	0.91	0.18	0	0.11	0.17
NO_3-N (mg/l)	0.38	1.40	0.64	0	0.38	0.96	0.26	0.70	0.15	0.03	0.42	0.48
PO_4-P (mg/l)	0	0	0.07	0	0.07	0.14	--	0.50	0.04	0.13	0.05	0.03

Table 28. Nitrogen and phosphorus in precipitation samples from Northeast Experiment Station, Nebraska.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970												
Precip. (cm)	—	—	—	—	—	—	—	—	10.90	6.45	3.84	1.07
No. of events	—	—	—	—	—	—	—	—	10	10	6	1
NH_4-N (mg/1)	—	—	—	—	—	—	—	—	0.29	0.40	1.71	2.07
NO_3-N (mg/1)	—	—	—	—	—	—	—	—	0	0.20	0.71	0.43
PO_4-P (mg/1)	—	—	—	—	—	—	—	—	0.06	0.80	0	Tr
1971												
Precip. (cm)	0.20	5.56	0.48	4.55	5.26	27.00	5.16	1.42	2.13	7.77	3.00	1.57
No. of events	—	3	2	6	10	12	9	3	5	9	7	4
NH_4-N (mg/1)	1.40	2.57	3.31	—	1.36	1.89	2.01	—	1.45	0.88	2.27	2.45
NO_3-N (mg/1)	0.48	0.90	2.06	—	0.53	0.23	0.94	—	0.44	0.50	1.13	1.07
PO_4-P (mg/1)	0.10	Tr	0.09	0.85	0.06	0.17	0.16	—	0.18	0.02	0.03	0.16
1972												
Precip. (cm)	0.38	—	2.16	5.33	12.37	4.47	19.94	3.51	13.77	3.91	2.64	4.98
No. of events	2	—	6	9	9	9	9	9	14	10	6	4
NH_4-N (mg/1)	1.38	—	—	2.70	3.12	5.36	0.40	8.36	1.49	1.72	4.36	3.19
NO_3-N (mg/1)	0.88	—	—	1.54	[illegible]	5.22	0.18	0.64	0.29	0.70	2.22	0.96
PO_4-P (mg/1)	0.02	—	0.03	0.07	0.21	0.22	0.04	—	0.09	0.18	0.01	0.01
1973												
Precip. (cm)	1.70	0.58	11.66	—	9.42	5.97	14.00	—	—	—	—	—
No. of events	5	3	9	—	7	4	11	—	—	—	—	—
NH_4-N (mg/1)	0.76	0.29	1.61	4.85	1.43	2.66	1.40	—	—	—	—	—
NO_3-N (mg/1)	0.15	0.12	0.58	1.70	0.70	6.73	0.56	—	—	—	—	—
PO_4-P (mg/1)	0	0.03	0	0.25	0.14	—	0.27	—	—	—	—	—

Table 29. Nitrogen and phosphorus in precipitation samples from Mead, Nebraska.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970												
Precip. (cm)	—	—	—	—	—	—	—	—	10.72	10.72	3.78	2.31
No. of events	—	—	—	—	—	—	—	—	10	10	10	5
NH_4-N (mg/1)	—	—	—	—	—	—	—	—	0.29	0.40	0.71	1.79
NO_3-N (mg/1)	—	—	—	—	—	—	—	—	0	0.20	0.50	1.86
PO_4-P (mg/1)	—	—	—	—	—	—	—	—	0.01	0	0	0.10
1971												
Precip. (cm)	0.48	3.10	0.41	2.43	19.76	7.19	3.81	2.54	1.80	11.20	6.10	1.50
No. of events	1	10	5	8	6	11	11	5	6	10	10	4
NH_4-N (mg/1)	0.150	1.38	1.38	1.26	0.68	0.91	1.59	0.93	1.13	0.06	0.76	1.45
NO_3-N (mg/1)	1.00	0.82	0.82	0.50	0.68	0.48	0.91	0.96	1.32	0.06	0.63	1.51
PO_4-P (mg/1)	0.05	0.03	0.03	0.11	0.05	0.24	0.16	0.04	0.05	0.02	0.03	0
1972												
Precip. (cm)	0.10	—	1.93	12.32	21.74	4.95	6.17	7.77	6.73	7.54	8.92	3.40
No. of events	—	—	6	11	15	8	8	8	9	9	9	4
NH_4-N (mg/1)	—	—	2.32	0.81	0.78	1.18	0.63	0.32	0.40	1.08	0.99	1.17
NO_3-N (mg/1)	—	—	1.56	0.36	0.43	0.76	0.60	0.23	0.11	0.32	0.64	0.70
PO_4-P (mg/1)	—	—	0	0.02	0.01	0.16	0.02	0.04	0.06	0.13	0.01	0
1973												
Precip. (cm)	2.67	0.89	12.93	3.40	12.60	4.95	14.52	1.30	16.00	10.54	4.83	3.45
No. of events	6	4	12	8	13	8	11	5	11	7	5	7
NH_4-N (mg/1)	1.20	1.90	1.02	0.96	1.05	1.14	0.67	1.05	0.38	0.09	2.27	0.48
NO_3-N (mg/1)	0.58	0.53	0.47	0.64	0.38	0.50	0.41	1.32	0.15	0	0.01	0.70
PO_4-P (mg/1)	0.01	0	0	0	0.09	0.12	0.05	0.23	0	0	0.01	0

Table 30. Nitrate-N in precipitation in Wooster, Ohio.

Month	Total Precip.	Precip. sampled	No. of events[a]	NO_3-N		
				Range	Mean	kg/ha
	cm	cm			mg/l	
			1973			
May	14.17	7.11	22(4)	1.95–3.80	2.61	3.69
June	12.14	3.78	15(2)	1.50–2.25	1.87	2.25
July	8.53	4.98	11(2)	1.15–1.28	1.21	1.03
Aug.	8.18	5.21	8(2)	1.10–1.18	1.14	0.93
Sept	5.46	3.12	4(1)	---	1.24	0.67
Oct.	8.74	4.22	10(2)	0.78–1.20	1.09	0.98
Nov.	6.58	1.80	7(1)	---	2.08	1.37
Dec.	5.87	3.10	15(2)	0.34–0.41	0.37	0.21
Total	69.67	33.32	92(16)			11.13
			1974			
Jan.	7.52	3.45	11(3)	0.04–0.24	0.16	0.11
Feb.	3.81	0.84	10(1)	---	0.57	0.21
March	11.58	5.59	18(3)	0.44–1.20	0.66	0.76
April	6.99	3.84	12(3)	0.16–0.68	0.44	0.30
Total	29.90	13.73	51(10)			1.38
Yearly Total	99.57	47.05	143(26)			12.51

[a] Figures in parentheses are number of events analyzed.

Table 31. Summary of precipitation chemistry for the period 1975-1977, Hotyville, Ohio.

	Sediment	PO_4-P	Total P	NH_4-N	(NO_3+NO_2)-N	Total N	Ca	Mg	K	CO_3^{3-}	Na	HCO	E.C.[a]
						mg/l							
No of samples	14	5	11	8	9	6	3	3	3	3	3	3	3
Range	2-24	0.012-0.065	0.00-0.80	0-1.5	0.0-1.7	0.8-3.9	0-1.5	0-0.4	0.4-0.7	0	0.0-0.5	15.9-24.6	38-54
Mean	11	0.036	0.19	0.3	0.8	1.9	0.8	0.2	0.6	0	0.2	19.3	44
S.D.	5.8	0.025	0.23	0.5	0.7	1.1	0.8	0.2	0.2	0	0.3	4.6	8.7

[a] Electrical couductivity, micromhos/cm.

Table 32. Nutrients in precipitation in Brookings, South Dakota.

Month	Precip.[a]	No of events[b]	NH_4-N	NO_3-N	Total P	Sol P	Ca	Mg	K	Na
	cm		mg/l[c]							
					1974					
July	4.98(3.66)	9(3)	1.80(0.66)	1.20(5.02)	0.15(0.05)	0.13(0.05)	4.80(1.76)	1.10(0.40)	10.5 (3.85)	1.20(0.44)
Aug.	7.54(3.91)	10(2)	0.81(0.32)	0.83(0.33)	0.05(0.02)	0.01(0.01)	1.80(0.70)	0.57(0.22)	1.80(0.70)	2.10(0.82)
					1975					
July	1.96(1.04)	7(1)	0.94(0.10)	0.54(0.06)	0.13(0.01)	0.10(0.01)	—	—	1.33(0.14)	1.67(0.17)
Aug.	11.79(10.16)	12(6)	2.02(1.03)	1.95(1.98)	0.17(0.17)	0.21(0.22)	2.97(0.43)	1.2 (0.17)	1.53(1.56)	1.53(1.56)
Sept.	10.19(9.73)	9(6)	1.84(0.88)	0.65(0.63)	1.43(1.39)	0.03(0.03)	3.64(3.54)	3.81(3.71)	0.83(0.81)	1.36(1.32)
					1976					
June	6.81(0.20)	5(1)	0.28(0.01)	0.39(0.01)	0.04(0)	0.03(0)	—	—	1.73(0.04)	—
July	3.84(3.30)	5(4)	1.16(0.38)	0.70(0.23)	0.11(0.04)	0.04(0.0)	—	—	2.20(0.73)	—
Aug.	5.13(4.14)	4(3)	0.99(0.41)	0.69(0.28)	0.22(0.09)	0.15(0.06)	—	—	2.26(0.94)	—
Sept.	4.06(3.96)	4(3)	0.87(0.35)	0.41(0.16)	0.04(0.82)	0.04(0.02)	—	—	1.45(0.58)	—
					1977					
May	5.49(0.58)	10(2)	0.89(0.05)	0.77(0.04)	0.24(0.01)	0 (0)	—	—	0.55(0.03)	—
June	18.57(17.78)	10(7)	1.16(2.06)	0.95(1.69)	0.28(0.50)	0.07(0.12)	—	—	1.19(2.12)	—
July	4.42(1.32)	8(3)	1.81(0.28)	0.79(0.12)	0.09(0.01)	0.07(0.01)	—	—	1.07(0.16)	—
Aug.	12.78(9.65)	13(7)	1.00(0.96)	0.52(0.50)	0.12(0.10)	0.02(0.02)	—	—	0.40(0.39)	—
Sept.	9.40(3.56)	10(4)	0.77(0.25)	0.52(0.19)	0.03(0.11)	0.02(0.09)	—	—	0.36(0.13)	—
Oct.	5.94(2.46)	7(1)	0.66(0.16)	0.31(0.08)	0.01(0.01)	0 (0)	—	—	0.23(0.06)	—
					1978					
June	7.34(0.31)	12(2)	0.65(0.03)	0.62(0.03)	0.07(0)	0.01(0)	—	—	0 (0)	—
July	10.24(8.05)	12(8)	0.76(0.61)	0.56(0.45)	0.17(0.14)	0.07(0.06)	—	—	0.43(0.35)	—
Aug.	5.72(3.00)	9(3)	0.88(0.26)	0.45(0.13)	0.06(0.02)	0.04(0.01)	—	—	0.28(0.09)	—
Sept.	6.20(5.77)	6(3)	0.79(0.56)	0.45(0.26)	0.08(0.05)	0.05(0.03)	—	—	0.09(0.58)	—
Oct.	0.89(0.25)	5(1)	0.63(0.28)	0.83(0.02)	0.04(0)	0.05(0)	—	—	0.90(0.02)	—

[a] Figures in parentheses are amount of precipitation analyzed.

[b] Figure in parentheses is number of events analyzed.

[c] Figures in parentheses = kg/ha/month.

Table 33. Concentration and deposition of some nutrients in precipitation in Drummond, Wisconsin[a] (data provided by Bill Kappel, Chequamegon National Forest).

	Average concentration[b]			Average deposition		
Parameter	Rain	Snow	Vol. Wtd. Avg.	Rain	Snow	Annual
	mg/l			kg/ha/yr		
Total P	0.018	0.032	0.021	0.11	0.05	0.16
Sol. P	0.004	0.004	0.004	0.03	0.02	0.05
Total N	0.73	0.79	0.74	4.56	1.18	5.74
NH_4-N	0.24	0.10	0.21	1.50	0.15	1.65
NO_3-N	0.34	0.40	0.35	2.12	0.60	2.72
Cl	0.54	0.48	0.53	3.38	0.72	4.10
	units					
pH	6.0	4.7	5.7	—	—	—
	μmhos					
Conductivity at 25°C	17	16	17	—	—	—

[a] 62.5 cm of rain and 15.0 cm of snow (77.5 cm average total annual precipitation).

[b] 5 snow samples and 22 rain samples, 1977-78.

Table 34. Average monthly concentration and deposition of nitrogen and sulfur at various sites in Wisconsin

Site Period	NH_4-N		NO_3-N		Org. N		SO_4-S	
	Conc.[a]	Deposition	Conc.	Deposition	Conc.	Deposition	Conc.	Deposition
	mg/l	kg/ha	mg/l	kg/ha	mg/l	kg/ha	mg/l	kg/ha
Antigo								
1969(May-Oct)	0-1.05(0.34)	0.23	0.23-1.37(0.52)	0.31	0.23-2.15(1.08)	0.76	2.2-3.8(2.72)	1.77
1970(March-Sept)	0.05-1.27(0.41)	0.20	0-1.02(0.40)	0.21	0.34-2.18(0.94)	0.72	0.5-2.5(1.11)	0.56
1971(April)	— (0.64)	0.62	— (0.70)	0.67	— (1.62)	1.54	— (3.00)	0.29
Alma								
1969(Oct-Dec)	0.55-7.69(3.05)	0.19	0.37-7.69(2.99)	0.05	— (0.09)	0.67	22.0-52.5(34.5)	6.94
1970(Jan-Dec)	0-5.25(1.29)	0.48	0-1.88(0.50)	0.13	0.64-5.98(2.49)	1.11	8.8-102(55.1)	16.0
1971(Jan-Apr)	1.36-17.7(6.39)	0.89	0.86-3.01(2.04)	0.38	1.29-14.7(5.43)	0.78	5.5-145(100)	20.0
Arlington								
1969(May-Dec)[b]	3.27-15.4(3.76)	1.47	0.37-1.24(0.72)	0.40	0.60-41.7(6.75)	1.48	3.8-23.5(10.3)	2.51
1970(Jan-Dec)	0-7.56(2.65)	1.35	0-1.78(0.62)	0.28	0.05-10.5(3.39)	1.28	0-14.5(6.47)	3.39
1971(Jan-Apr)	1.02-6.94(3.19)	0.88	0.91-1.47(1.08)	0.35	1.35-3.93(2.90)	0.97	3.8-38.5(18.3)	5.00
Ashland								
1969(May-Dec)	0.14-1.24(0.52)	0.22	0.18-1.01(0.43)	0.20	0-3.16(0.85)	0.40	2.0-8.0(3.66)	1.78
1970(Jan-Dec)	0-2.75(0.80)	0.46	0-3.20(0.96)	0.30	0.05-5.13(1.13)	0.48	0-11.6(2.95)	0.60
1971(Jan-Apr)	0.41-2.26(1.40)	0.51	0.34-2.20(1.37)	0.49	0.71-2.19(1.53)	0.48	1.5-9.0(4.88)	1.83
Briess								
1969(May-Sept)	0.92-4.03(2.30)	0.81	0.09-3.11(0.92)	0.25	1.09-15.6(5.46)	1.00	2.8-4.5(3.38)	1.66
1970(Mar-Sept)	0.15-2.68(1.19)	0.49	0-2.46(0.58)	0.17	0.77-3.78(1.44)	1.51	0.2-5.0(1.94)	1.12
1971(Mar-Apr)	2.90-8.23(5.57)	1.71	0.59-1.67(1.13)	0.35	1.94-6.82(4.38)	1.36	2.5-7.0(4.75)	0.15
Dierauer								
1969(Sept-Dec)	0.25-0.49(0.39)	0.31	0.20-0.46(0.33)	0.24	0.10-1.17(0.60)	0.26	0-6.0(2.93)	1.18
1970(Jan-Apr)	1.02-4.25(2.03)	0.58	0.56-2.31(1.24)	0.37	0.70-3.49(1.69)	0.46	3.0-27.0(9.63)	3.45
Douglas								
1969(May-Oct)	0.37-2.88(1.80)	1.07	0.05-0.96(0.39)	0.24	1.65-4.12(3.86)	3.86	3.8-7.8(4.80)	2.60
1970(Mar-Sept)	0.69-12.6(3.18)	2.71	0-0.87(0.41)	0.26	0.34-3.63(1.83)	1.72	0.2-3.2(1.36)	0.89
1971(Mar-Apr)	0.81-3.66(2.24)	0.72	0.86-0.97(0.92)	0.32	2.85-4.08(3.47)	1.18	2.5-4.0(3.25)	0.11
Duninger								
1969(Sept-Nov)	0-1.62(1.00)	1.01	0.05-0.66(0.33)	0.35	0-1.78(1.17)	1.85	0.8-5.2(2.27)	0.83
1970(Mar-Apr)	1.67-2.47(2.07)	0.91	0.70-1.24(0.97)	0.41	6.07-8.07(7.07)	3.26	3.5-4.5(4.0)	1.84
Ellefson								
1969(May-Oct)	0.50-6.00(3.43)	1.62	0.28-1.10(0.56)	0.26	2.43-9.93(4.31)	2.01	0-5.5(2.67)	1.22
1970(Mar-Aug)	0-6.73(1.64)	1.71	0.10-0.74(0.43)	0.40	0.49-2.91(1.19)	1.07	0-1.8(0.37)	0.21
Hancock								
1969(May-Dec)	0.32-9.70(3.03)	1.44	0.27-2.38(0.74)	0.19	0.41-8.84(2.50)	0.99	2.0-5.0(3.54)	1.80
1970(Jan-Dec)	0.10-2.70(1.05)	0.64	0.15-5.69(1.26)	0.42	0-3.21(0.87)	0.42	0-29(6.29)	1.48
1971(Jan-Apr)	0.71-1.67(1.22)	0.59	0.81-1.72(1.23)	0.35	0.61-1.32(0.95)	0.35	2.5-43(17.3)	4.97
Marsh								
1969(May-Dec)	0-1.19(0.77)	0.38	0-7.74(1.90)	0.09	0-8.05(4.16)	2.18	0-14(4.60)	3.13
1970(Apr-Aug)	0.34-7.56(2.24)	1.00	— —	0.44	0.14-4.02(1.74)	1.10	0-6.2(1.60)	0.54
Jacobson								
1969(May-Oct)	0.09-11.6(2.75)	1.35	0.05-0.46(0.20)	0.11	1.19-14.5(4.61)	2.18	2.0-4.8(3.30)	1.83
1970(Mar-Sept)	0-6.73(1.15)	1.08	0-0.26(0.08)	0.07	0.77-1.76(1.23)	0.99	0-2.0(0.31)	0.26
1971(Mar-Apr)	0.48-2.85(1.67)	2.14	0.29-0.32(0.31)	0.41	1.24-9.73(5.49)	7.03	2.0-3.5(2.75)	1.62
LaCrosse								
1969(May-Oct)	0-9.52(2.68)	2.49	0-0.64(0.14)	0.07	0.37-2.79(1.58)	0.96	0.2-2.0(0.80)	0.43
1970(Apr-Sept)	0.10-15.6(3.14)	4.21	0.19-0.44(0.21)	0.16	0.49-2.99(1.89)	1.51	0-1.5(0.95)	0.50
1971(April)	0.40	0.18	— —	—	4.47	1.50	1-5	0.57
Lake Mills								
1969(May-Oct)	0.64-8.29(3.62)	2.74	0.32-1.44(0.78)	0.41	0-5.50(1.76)	0.92	1.8-5.8(3.53)	2.31
1970(Mar-Sept)	0.83-5.32(2.24)	1.65	0.36-1.02(0.74)	0.53	0.54-3.98(3.12)	2.38	0.2-4.5(2.27)	1.64
1971(Mar-Apr)	0.81-3.66(2.24)	0.99	1.08-1.88(1.48)	0.52	3.28-5.16(4.22)	1.68	5.5-8.5(7.0)	2.77
Lancaster								
1969(May-Dec)	0.27-4.58(1.22)	0.42	0.09-0.73(0.38)	0.19	0-4.03(1.32)	0.49	1.2-8.0(3.55)	1.54
1970(Jan-Dec)[c]	0-8.98(2.30)	0.74	— —	0.22	0-3.56(1.16)	0.82	0-1.35(20.3)	4.66

[a] Range and mean.

[b] Excluding Feb. and Nov.

[c] Excluding Nov.

Table 34. Continued

Site Period	NH_4-N		NO_3-N		Org. N		SO_4-S	
	Conc.	Deposition	Conc.	Deposition	Conc.	Deposition	Conc.	Deposition
	mg/l	kg/ha	mg/l	kg/ha	mg/l	kg/ha	mg/l	kg/ha
Madison								
1969(May-Oct)	0-1.01(0.20)	0.16	0-1.74(0.43)	0.24	0.36-2.66(1.16)	0.57	3.5-8.0(4.65)	2.50
1970(Mar-Sept)	0-1.56(0.39)	0.36	0-0.39(0.17)	0.14	0-1.86(0.86)	0.49	0.2-8.8(3.49)	1.81
1971(Mar-Apr)	0.54-0.75(0.65)	0.31	1.02-1.22(1.12)	0.33	0.75-2.04(1.40)	0.39	3.5-6.0(4.75)	2.08
Marshfield								
1969(May-Dec)	0.14-2.20(0.83)	0.36	0.23-0.92(0.34)	0.22	0.16-2.10(0.39)	0.29	2.8-12(5.81)	2.21
1970(Jan-Dec)	0.41-3.68(1.54)	0.72	0.20-4.22(0.71)	0.29	0.20-4.64(1.71)	0.69	0.2-54(14.7)	4.03
1971(Jan-Apr)	0.10-3.01(1.46)	0.36	0.10-4.52(2.14)	0.76	0.41-7.63(3.91)	0.49	6.3-42(24.0)	9.26
Oshkosh								
1969(May-Oct)	0.09-5.43(1.28)	0.95	0.14-0.78(0.45)	0.34	0.45-8.65(2.36)	1.63	2.0-4.5(3.02)	2.15
1970(Mar-Sept)	0.2[illegible]-1.08(0.60)	0.40	0.15-1.12(0.47)	0.28	0.44-1.57(0.94)	0.61	0-2.2(0.93)	0.30
1971(Mar-Apr)	1.45-3.01(2.23)	0.63	0.91-1.40(1.16)	0.32	1.78-3.23(2.50)	0.71	4.0-6.0(5.00)	1.38
Spooner								
1969(May-Dec)	0.09-1.65(0.73)	0.30	0.11-0.50(0.31)	0.14	1.56-9.02(3.30)	1.35	2.0-7.5(3.69)	1.28
1970(Jan-Dec)	0-5.51(1.32)	0.24	0.05-2.17(0.57)	0.20	0.10-6.85(1.41)	0.44	0-57(7.23)	0.78
1971(Jan-Apr)	0.25-1.72(1.07)	0.35	0.41-2.58(1.15)	0.33	0.05-1.83(0.96)	0.18	2.0-[illegible]1(7.50)	1.84
Segerstrom								
1969(May-Oct)	0.27-6.96(1.90)	0.37	0.23-0.55(0.47)	0.15	0.73-17.0(6.00)	0.69	2.0-7.5(3.65)	0.95
1970(Mar-Aug)[a]	0.54-7.13(2.41)	1.20	0.05-0.29(0.16)	0.12	0.50-20.8(5.43)	1.28	0-3.8(1.62)	0.52
Sturgeon Bay								
1969(May-Dec)	0.28-1.10(0.62)	0.39	0.37-0.92(0.53)	0.31	0.09-5.03(1.39)	1.26	2.2-9.2(4.15)	1.95
1970(Jan-Dec)	0.15-2.10(1.15)	0.63	0.20-4.53(0.98)	0.39	0.15-7.49(2.16)	1.19	0.8-67(11.8)	4.03
1971(Jan-Apr)[b]	1.02-3.68(2.32)	2.01	1.27-1.45(1.37)	1.17	0-4.30(1.60)	0.67	5.5-12(8.50)	8.17
Young								
1969(May-Oct)	2.88-11.0(4.50)	2.40	0.46-0.78(0.61)	0.30	0-4.80(1.95)	0.85	1.0-4.5(3.12)	1.48
1970(Mar-Dec)	0.44-8.36(2.44)	1.78	0.15-0.97(0.44)	0.35	0.10-5.09(1.15)	0.74	0-5.0(1.26)	1.14
1971(Jan-Apr)	1.37-11.7(4.90)	1.24	0.61-1.19(0.92)	0.30	0.86-4.25(2.13)	0.60	2.5-19(7.25)	1.64
Waukesha								
1969(May-Oct)	0.09-1.46(0.68)	0.25	0.37-1.53(0.63)	0.35	0.59-1.83(1.10)	0.88	2.8-4.8(3.53)	2.34
1970(Mar-Sept)	0-0.82(0.41)	0.26	0-1.17(0.68)	0.45	0.20-1.61(0.94)	0.64	0-4.5(2.09)	1.26
1971(Mar-Apr)	0.91-1.77(1.34)	0.39	0.91-1.08(1.00)	0.23	1.89-2.42(2.16)	0.48	1.5-3.5(2.5)	0.75

[a] Excluding July.

[b] Excluding March.

lar to that in Minnesota (6-14 kg/ha) and Nebraska (6-20 kg/ha), but higher than the amounts accumulated at various sites in Wisconsin (Table 34). In addition to these amounts of inorganic N added by precipitation, NH_4-N could be directly absorbed by soil surface, especially in areas near feedlots (Hutchinson and Viets, 1969).

Junge (1958) conducted a nationwide survey of NH_4-N and NO_3-N in rainwater samples of 60 sites in the United States during 1955 and 1956. He found an uneven distribution of both these forms of inorganic N in rainwater. Also he found no correlation between these inorganic N forms in precipitation and thunderstorm activity, density of industry, population, or agricultural activity. He found, however, that areas having soils of low pH values correlated with areas having low concentration of NH_4-N in precipitation and that alkaline-soil regions seemed associated with a high concentration of NH_4-N in rainwater. The results summarized in this work were not aimed toward investigating such relationships, but the results obtained for concentrations of NH_4-N in precipitation samples at the six sites in Iowa do not seem to show any general trend to indicate such relationships.

Sulfur in precipitation

Compared with the information available about N in precipitation in the North Central Region, little data have been obtained on concentration and accumulation of S in precipitation in this region. The information available is from Iowa (Tables 9 and 10), Michigan (Table 16), Minnesota (Tables 21 and 22), Nebraska (Table 24), and Wisconsin (Table 34). The annual accumulation of S by precipitation ranged from 5 kg/ha in Nebraska (Table 24) and Wisconsin (Table 34) to about 17 kg/ha in Iowa (Table 10) and Michigan (Table 16). Sulfur deposition as high as 20 kg/ha has been reported for one site (Alma) in Wisconsin (Table 34).

Results reported for concentration of SO_4-S in precipitation in Iowa (Tabatabai and Laflen, 1976) indicate that it is seasonal and inversely related to the amount of monthly precipitation. The greater concentration of SO_4-S was found during the fall and winter when precipitation is low, and the least concentration during the summer and spring when precipitation is heavy. Atmospheric S levels in Wisconsin at rural and urban sites also were low in the summer and high in the winter (Hoeft et al., 1972). The high concentration of SO_4-S in precipitation during the fall and winter in this area could be due to home and business heating during these months. The low concentrations during the spring and summer could be due to washing by precipitation and to lower concentration of S gases in the atmosphere resulting from direct absorption of SO_2 and other S gases by the exposed soil and plant surfaces. These processes of addition and removal of S gases into and from the atmosphere seem to play major roles in the observed seasonal concentration of SO_4-S in precipitation in some sites in this region.

The concentration of SO_4-S and, therefore, its accumulation seems not to have changed significantly in the region within the past decades. For example, the average annual additions of S by precipitation (16 kg/ha) during 1971-1973 in Iowa and (17 kg/ha) during 1969-1971 in rural areas of Wisconsin are similar to that reported over a half century ago for Iowa (Tabatabai and Laflen, 1976; Hoeft et al., 1972). Erdman (1923) estimated the annual precipitation-originated S in Ames, Iowa, in 1923 to be 17 kg/ha, and the present estimate for this site is 17 kg/ha. Also, Harper (1942) summarized the data that were available before 1942, indicating that rural areas of the United States were receiving precipitation-originated S in amounts similar to those found currently in this region.

No detailed information is available on variation in deposition of S by precipitation in this region, but the data accumulated for S in precipitation over Iowa indicate that between 62 and 78% of the S is deposited during the spring and summer (Tabatabai and Laflen, 1976). The amounts of S (5-15 kg/ha annually) added by precipitation in the North Central Region are important to crop production because laboratory tests and field and greenhouse experiments have shown that some soils of this region do not contain sufficient plant-available S to meet crop requirements for this element (Fox et al., 1964; Seim et al., 1969; Tabatabai and Bremner, 1972; Widdowson and Hanway, 1974), yet no S deficiency symptoms have been widely reported. From the results summarized in this report, it is evident that precipitation adds the small amounts of S required by many crops in this region. Also, some S gases likely are absorbed directly by soils and plants because it is known that soils and plants absorb SO_2 directly from the atmosphere (Allway et al., 1937; Coleman, 1966; Faller, 1970; Olsen, 1957; Ulrich et al., 1967). A study in Wisconsin showed that, under optimum yield, 44% of the S in alfalfa was obtained from atmospheric sources (Hoeft et al., 1972). The concentrations and accumulations of S by precipitation and those reported in soils from the North Central Region (Tabatabai and Bremner, 1972; Widdowson and Hanway, 1974; Seim et al., 1969) indicate that current concentrations and accumulation of S by precipitation in this region are beneficial to crop production.

Phosphorus in precipitation

The concentration and accumulation of P by precipitation in the North Central Region are very small relative to those of N and S. This is mainly because no P gases are emitted into, or exist in, the atmosphere; the only sources of P in precipitation are airborne particulate matters, mostly dust. Normally the concentration of soluble PO_4-P in precipitation is in the ppb levels. The annual deposition of P does not exceed a fraction of kg/ha. In this report, results have been summarized for Indiana (Tables 5-8), Michigan (Tables 13-15), Minnesota (Tables 21-23), Nebraska (Tables 24-29), Ohio (Table 31), South Dakota (Table 32), and Wisconsin (Table 33). The annual accumulation of P ranged from < 0.1 to 1 kg/ha. These amounts are insignificant compared with those present in soils and added by fertilizers.

Other elements in precipitation

Precipitation may contain K, Na, Ca, and Mg. These elements originate mainly from particulates and dust materials suspended in the atmosphere. Information on K, Na, Ca, and Mg in precipitation is available from Minnesota (Tables 21-23), Ohio (Table 31), and South Dakota (Table 32). The data indicate that the annual deposition of these elements may range from < 1 to 10 kg/ha (Tables 21-23 and 32).

Emission of particulates and gaseous pollutants

The concentration and accumulation of nutrients by precipitation are directly related to their concentrations in the atmosphere, especially the elements that could be present in the atmosphere in gaseous forms (e.g., N and S). Table 35 shows the total emission of particulates, SO_x, NO_x, hydrocarbons, and CO from fuel combustion (from point and nonpoint sources) in the states in the North Central Region. Generally, the least emission is in South Dakota, and the greatest in Ohio, a fact reflecting the industrial activities in the region. The amounts of these materials emitted from industrial processes (point sources), solid waste disposal, transportation (nonpoint sources), and other miscellaneous sources in each state in the region are reported in Tables 36, 37, 38, and 39, respectively. Fuel combustion from point sources is contributing manyfold more SO_x and NO_x than that from nonpoint sources (Table 35). Industrial processes (point sources) such as chemical manufacturing and food and agricultural processing are contributing low degrees of air pollution by SO_x and NO_x in Nebraska, North Dakota, and South Dakota. The states contributing a high degree of air pollution by these oxides from these sources are Illinois, Michigan, and Ohio.

With the exception of the states of Illinois, Michigan, and Nebraska, the amounts of SO_x and NO_x emitted into the atmosphere from solid waste disposal from nonpoint sources exceed those emitted from point sources (Table 37). Transportation contributes great

(text continues on page 141)

Table 35. Emission of particulates, SO_x, NO_x, hydrocarbons, and carbon monoxide from fuel combustion in the states of the North Central Region.

State	Source[a]	Particulates	SO_x	NO_x	HC	CO
		ton/year				
Illinois	Point	229,259	1,959,220	632,523	6,877	22,382
	Nonpoint	149,937	140,516	88,807	11,022	48,132
Indiana	Point	226,586	1,518,217	551,780	11,828	25,921
	Nonpoint	260,080	114,904	43,015	3,335	13,972
Iowa	Point	47,004	256,611	101,445	2,534	5,098
	Nonpoint	5,855	6,625	10,755	1,253	4,047
Kansas	Point	6,103	116,001	158,560	4,927	5,488
	Nonpoint	927	2,063	8,678	713	1,845
Michigan	Point	116,302	941,530	277,975	5,469	14,605
	Nonpoint	6,610	22,662	42,618	3,260	20,057
Minnesota	Point	31,987	207,743	97,474	4,285	8,013
	Nonpoint	12,322	24,426	24,406	1,696	8,405
Missouri	Point	71,274	1,167,476	294,805	3,469	10,947
	Nonpoint	148,285	69,062	29,475	3,663	18,450
Nebraska	Point	8,802	28,351	39,614	2,201	2,311
	Nonpoint	1,230	4,700	9,971	689	2,560
North Dakota	Point	10,353	79,609	45,414	1,226	3,459
	Nonpoint	5,403	10,191	4,400	630	2,576
Ohio	Point	421,817	2,772,779	658,033	11,704	35,686
	Nonpoint	269,401	107,051	61,164	7,227	29,770
South Dakota	Point	6,693	31,091	21,701	203	453
	Nonpoint	670	1,218	2,009	294	1,500
Wisconsin	Point	177,335	531,209	158,724	3,045	14,796
	Nonpoint	14,715	26,771	22,907	3,061	13,602

[a] Point sources include all types of fuels used in external and internal combustions. Nonpoint sources include all types of fuels used for residential, industrial, and commercial heating.

Table 36. Emission of particulates, SO_x, NO_x, hydrocarbons, and carbon monoxide from industrial processes (point sources) in the states of the North Central Region.[a]

State	Particulates	SO_x	NO_x	HC	CO
	ton/year				
Illinois	381,064	121,942	48,219	232,161	517,709
Indiana	86,072	54,190	25,930	134,799	346,391
Iowa	144,849	32,251	3,642	16,176	52,827
Kansas	151,694	41,394	18,531	99,328	9,771
Michigan	92,575	120,452	15,413	193,471	327,616
Minnesota	79,821	23,774	3,954	120,585	27,420
Missouri	89,613	128,245	15,114	109,268	38,434
Nebraska	100,143	13,023	4,032	51,690	5,618
North Dakota	8,852	17,727	843	1,816	275
Ohio	405,453	113,563	20,378	231,457	220,745
South Dakota	29,896	3,470	885	4,128	0
Wisconsin	51,231	37,141	42,422	157,830	50,737

[a] Chemical manufacturing, food and agricultural processing, primary metals processing, secondary metals processing, petroleum industry, wood products, organic solvent evaporation, petroleum storage and transport, metal fabrication, and other not classified sources.

Table 37. Emission of particulates, SO_x, NO_x, hydrocarbons, and carbon monoxide from solid waste disposal in the states of the North Central Region.

State	Source[a]	Particulates	SO_x	NO_x	HC	CO
		ton/year				
Illinois	Point	14,098	2,279	1,938	6,414	27,033
	Nonpoint	7,009	101	219	19,698	59,087
Indiana	Point	639	269	796	532	1,154
	Nonpoint	19,273	1,496	4,048	41,298	120,157
Iowa	Point	142	22	84	104	274
	Nonpoint	23,270	2,202	8,726	40,017	112,312
Kansas	Point	21	12	5	53	328
	Nonpoint	18,880	959	4,487	41,846	121,693
Michigan	Point	3,457	1,683	11,323	4,985	6,784
	Nonpoint	10,240	1,128	2,337	19,747	56,783
Minnesota	Point	4,650	97	298	458	4,512
	Nonpoint	8,257	538	3,110	15,396	43,496
Missouri	Point	585	357	290	214	4,932
	Nonpoint	5,341	495	1,959	9,280	26,142
Nebraska	Point	1,129	121	543	259	678
	Nonpoint	851	49	321	1,591	4,528
North Dakota	Point	—	—	—	—	—
	Nonpoint	189	57	65	126	279
Ohio	Point	10,061	755	1,249	1,432	9,069
	Nonpoint	40,198	3,227	8,566	85,307	248,265
South Dakota	Point	694	14	120	1,171	12,733
	Nonpoint	2,447	115	327	5,960	17,583
Wisconsin	Point	3,275	450	812	864	6,444
	Nonpoint	19,230	1,627	3,925	40,681	118,394

[a] Point sources include: municipal incineration and industrial on site incineration and open burning. Nonpoint sources include: residential on site incineration and open burning, commercial and institutional on site incineration and open burning, and industrial on site incineration and open burning.

Table 38. Emission of particulates, SO_x, NO_x, hydrocarbons, and carbon monoxide from transportation (nonpoint sources) in the states of the North Central Region.[a]

State	Particulates	SO_x	NO_x	HC	CO
	ton/year				
Illinois	296,894	28,497	410,216	622,662	5,014,629
Indiana	135,707	18,958	237,043	285,611	2,144,593
Iowa	81,498	14,103	196,469	188,298	1,436,170
Kansas	68,615	9,522	132,721	166,105	1,254,767
Michigan	237,603	20,367	322,985	464,299	3,613,861
Minnesota	95,215	11,837	170,892	230,572	1,728,918
Missouri	136,177	15,566	233,118	308,756	2,397,395
Nebraska	43,012	7,858	98,644	110,639	862,826
North Dakota	14,789	3,185	40,983	43,873	335,315
Ohio	279,234	37,104	435,577	520,653	3,963,635
South Dakota	15,912	2,661	39,206	44,393	332,700
Wisconsin	109,904	12,323	179,840	248,293	1,940,858

[a] Including land vehicles using gasoline (light-duty vehicles, light-duty trucks, heavy-duty vehicles, and off-highway gasoline use) and diesel (heavy-duty vehicles, off-highway diesel use, and trains); aircrafts including military, civil, and commercial; and other vessels that use diesel fuel, residual oil, and gasoline.

Table 39. Emission of particulates, SO_x, NO_x, hydrocarbons, and carbon monoxide from miscellaneous sources (nonpoint sources) in the states of the North Central Region.[a]

State	Particulates	SO_x	NO_x	HC	CO
	ton/year				
Illinois	452,447	2	178	510,801	4,909
Indiana	254,845	0	220	226,405	6,917
Iowa	424,798	7	390	100,726	13,999
Kansas	619,944	32	1,678	91,773	66,498
Michigan	541,536	64	1,743	406,739	60,543
Minnesota	515,806	117	3,175	165,028	110,814
Missouri	401,905	8	512	194,942	17,626
Nebraska	391,164	0	148	47,985	5,307
North Dakota	541,435	1	60	14,515	2,083
Ohio	203,056	1	200	558,153	5,429
South Dakota	330,927	34	914	22,479	32,461
Wisconsin	245,152	19	670	207,334	23,020

[a] Including forest fires, structural fires, gasoline stations evaporation loss, unpaved roads, and unpaved airstrips.

Table 40. Total emission of particulates, SO_x, NO_x, hydrocarbons, and carbon monoxide in the states of the North Central Region.

State	Source	Particulates	SO_x	NO_x	HC	CO
		ton/year				
Illinois	Point	624,421	2,083,441	682,679	245,451	567,124
	Nonpoint	906,287	169,116	496,697	1,164,183	5,126,757
Indiana	Point	313,297	1,572,676	578,507	147,159	373,466
	Nonpoint	669,905	135,358	284,326	556,650	2,285,639
Iowa	Point	191,995	288,884	105,172	18,814	58,227
	Nonpoint	535,421	22,938	216,340	330,293	1,566,528
Kansas	Point	157,817	157,406	177,095	104,308	15,587
	Nonpoint	708,363	12,576	147,564	300,437	1,444,803
Michigan	Point	212,335	1,063,667	304,630	203,925	349,005
	Nonpoint	795,989	44,420	369,683	894,045	3,751,243
Minnesota	Point	116,458	231,615	101,726	125,328	39,945
	Nonpoint	631,601	36,919	201,583	412,693	1,891,634
Missouri	Point	161,473	1,296,079	310,209	112,950	54,314
	Nonpoint	691,707	85,131	265,063	516,640	2,459,612
Nebraska	Point	110,074	41,494	44,188	54,150	8,607
	Nonpoint	436,257	12,607	109,084	160,904	875,231
North Dakota	Point	19,205	97,335	46,256	3,044	3,734
	Nonpoint	561,816	13,434	45,508	59,145	340,253
Ohio	Point	837,331	2,887,097	679,661	244,593	265,500
	Nonpoint	791,890	147,383	505,507	1,171,339	4,247,099
South Dakota	Point	37,283	34,574	22,705	5,50[illegible]	13,229
	Nonpoint	349,956	4,028	42,456	73,126	384,245
Wisconsin	Point	231,844	568,800	201,958	161,739	71,976
	Nonpoint	389,000	40,740	207,341	499,369	2,095,874

Table 41. Emission of particulates, SO_x, NO_x, hydrocarbons, and carbon monoxide from all sources per unit surface area in the states of the North Central Region.

State	Total area	Particulates	SO_x	NO_x	HC	CO
	km^2	ton/km^2/year				
Illinois	146,076	10.5	15.4	8.1	9.7	39.0
Indiana	93,994	10.5	18.2	9.2	7.5	28.3
Iowa	145,791	5.0	2.1	2.2	2.4	11.1
Kansas	213,063	4.1	0.8	1.5	1.9	6.9
Michigan	150,779	6.7	7.3	4.5	7.3	27.2
Minnesota	217,736	3.4	1.2	1.4	2.5	8.9
Missouri	180,486	4.7	7.7	3.2	3.5	13.9
Nebraska	200,018	2.7	0.3	0.8	1.1	4.4
North Dakota	183,022	3.2	0.6	0.5	0.3	1.9
Ohio	106,764	15.3	28.4	11.1	13.3	42.3
South Dakota	199,552	1.9	0.2	0.3	0.4	2.0
Wisconsin	145,439	4.3	4.2	2.8	4.5	14.9

amounts of SO_x, NO_x, hydrocarbons, and CO to the atmosphere (Table 38). Total emission of these pollutants from all sources in each state in the region is shown in Table 40. Expressed in ton/km^2 annually, South Dakota and Nebraska contribute the least, and Ohio, Indiana, and Illinois, the most, to air pollution by these contaminants (Table 41).

Although there is a great degree of variation in emission of particulates, SO_x, and NO_x into the atmosphere among the states in this region, this variation is not readily evident in precipitation from the various sites. This seems to be due to mixing, transport, and dilution in the atmosphere and removal by wet and dry deposition of these atmospheric pollutants.

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June 8, 1982

The Honorable Senator Max Baucus
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Dear Senator Baucus:

On May 27, 1982, I had the privilege of attending a hearing on the effects of acid rain that was held by the Senate Committee on Environment and Public Works. During the Hearing, several of my scientific colleagues had the opportunity to describe some of the working hypotheses which we are actively debating. Some of the hypotheses mentioned were:

1. Atmospheric deposition with pH levels below 5.6 represents hydrogen anion concentrations that may harm the ecosystem.

2. The amount of sulfate in atmospheric deposition can be used as a surrogate for predicting the amount of hydrogen deposited, and hence the potential for acidification.

3. The extent of North American waters actually at risk from acidification can be identified using criteria based on soil type, soil chemistry, and bedrock geology.

4. Acidified water bodies are responsible for substantial losses to fish populations.

5. It is possible to predict atmospheric sulfate loading and emission

levels that may protect ecosystems from acidic precipitation.

6. Forest ecosystems may be at risk from acidic deposition.

7. Agricultural productivity may be affected by acidic deposition.

At the suggestion of Mr. Steve Rovig of your staff, I have enclosed my prepared written testimony "Comments on the Status of Knowledge Concerning the Effects of Acidic Precipitation on the Aquatic and Terrestrial Ecosystem." Mr. Rovig indicated to me that my prepared testimony will be entered into the Record as part of the May 27, 1982, acid deposition hearing. I appreciate your offer of assistance in this matter.

It is the uncertainty associated with the state of knowledge concerning acid rain used by certain researchers in the field that has resulted in my efforts to examine the current working hypotheses. The above-mentioned hypotheses must be evaluated before one can conclude whether or not acidic precipitation is causing harm to the environment. Recently, published articles have begun to change our thinking concerning the validity of some of these hypotheses. For purposes of clarification, the references contained with this letter can be found in the attached written testimony.

I. Atmospheric Chemistry

One important aspect of the acidic precipitation question is the definition of normal pH. It has been inferred that the normal pH of atmospheric deposition should be 5.6 and that pH values less than 5.6 imply the occurrence of possible detrimental impacts to the ecosystem from man made causes. A variety of studies conducted have revealed pH values below 5.6 in remote parts of the world and illustrated that resources should not always be considered at risk when pH values fall below 5.6. Recently, Charlson and Rodhe (1982) and Sequeira (1982) pointed out that the deposition pH values might range from 4.5 to 5.6 due to the variability of chemical atmospheric chemical components such as ammonium, bicarbonate, or sulfur dioxide. Furthermore, Sequeira and Coote et al. (1981) stressed that sulfate cannot be used as a surrogate for hydrogen ion concentration unless neutralizing atmospheric components are absent.

At the May 27, 1982, Hearing, Dr. Loucks presented a summary of his report which states that there may be an increase of 4% to 15% more lakes either becoming "acidified" or "extremely sensitive" to acid inputs by the year 2000. Under a slightly different scenario, Dr. Loucks has estimated that decreasing sulfate deposition by 20% by the year 2000 will cause recovery of 10-25% of the most sensitive lakes and streams. He further estimates that a 35% decrease in sulfate deposition by the year 2000 will result in a 16-41% recovery for the most sensitive aquatic resources.

Dr. Loucks has assumed that 1) aquatic resources at risk can be solely based on using "alkalinity" as an indicator for sensitivity and 2) the amount of sulfate in the atmosphere can be used to predict the amount of hydrogen that will be available to titrate the soil and aquatic components of the environment. As has been discussed above, several authors believe that sulfate cannot be used as a surrogate for the hydrogen ion. Based on my review of these scientific articles and the current NADP data base, I believe Dr. Louck's projections cannot be used to predict possible changes to the existing status of aquatic resources.

Dr. Louck's first assumption, that alkalinity can be used as the key indicator for predicting aquatic sensitivity, is too simplistic. The aquatic ecosystem is a complex system which defies simple models. In my accompanying written testimony, I have commented on this assumption.

II. Alteration of Aquatic Biotic Components

It has been hypothesized that alterations in biotic components are all caused by atmospheric deposition from long-range transport processes. Some of the data most often cited to support this inference is from Sudbury, Ontario. Documented cases of fish losses from the Sudbury, Ontario area are apparently due to the direct result of impacts from the Sudbury base-metal smelting operations. These operations may be the largest point source of atmospheric sulfur in the world (Beamish 1976).

Primarily in Adirondack lakes have losses of fish population (especially brook trout) been attributed to acidifying waters. Retzsch et al. (1982) have suggested possible explanations for several of the observations:

- The presence of extensive, naturally acidic wetlands (fens and bogs) and forest soils either near, or adjacent to, lakes, ponds, and streams.
- Environmental conditions such as low oxygen concentrations, extreme temperatures, high organic and hydrogen sulfide concentrations, and high pollutant (toxic metals and pesticide) concentrations.
- Changes in fish stocking and management efforts.
- Regional development and increased recreational activities.
- Alterations of natural habitats resulting from construction of dams (man-made or beaver) that manipulate stream flow or lake

levels.

It has been noted by other investigators that there are, at present, no indications of any adverse effects on the aquatic life of the lakes of the region from acidification (Patrick et al. 1981). Many streams of the Pine Barrens are naturally acidic (pH 4-5) and some lakes in the region are experiencing increases in pH as a result of eutrophication (Patrick et al. 1981).

The state of knowledge, concerning the relationship among atmospheric SO_4^{2-} concentrations, lake acidification, and fish populations (and other aquatic organisms) in the surface waters of North America, is limited. In virtually all regions having acid precipitation, poorly-buffered lakes maintain healthy fish communities. Thus, the cause and effect relationships between levels of sulfate in precipitation and effects on aquatic organism communities have not been adequately documented and may never be, due to the atmospheric chemical considerations mentioned earlier.

II. Forest Productivity

There have been several attempts made to define the relationship between forest productivity and acidic precipitation. As Senator Mitchell underscored in the hearing, no documented, scientific, field validated evidence exists for showing a direct effect of acidic precipitation on forests.

Dr. Arthur Johnson presented testimony that acidic precipitation may have had an effect on a forest ecosystem in the New Jersey Pine Barrens area. Dr. Johnson and his colleagues have attempted to correlate an abnormal decrease in growth of pitch pine with stream pH. The statistical analysis does not present a strong case for proving this correlation.

One of the major unexplained concerns in the New Jersey Pine Barrens is the reduced growth rate. The authors did investigate possible causes for decreased growth rate. They felt that the effects of pests were absent, as were effects of wildfire. Retention in appearance of needles was normal, and the authors believe that ozone did not cause damage.

When one reviews the ozone ambient air quality for the Pine Barrens area, it is evident that the ozone levels are high enough to cause injury and or damage. Feliciano (1972) and Pell (1973) reported air pollution damage to several counties near the New Jersey Pine Barrens area. In 1971, a survey of injury resulting from air pollution episodes and assessment of their resultant effect on crop production was conducted. Economic loss of crops due to air pollution was estimated at $1,183,800. Over one-fourth of the total crop losses were recorded in Cumberland County. Other counties where damages exceeded $100,000 were Burlington, Atlantic, and Salem. Feliciano (1972) attributed photochemical oxidant to 80 percent of the plant injury recorded. Pell (1973) reported that the total losses to crops for 1972 was $128,019. Forty-seven percent of the plant damage was caused by oxidants. Cumberland, Warren, Atlantic and Salem Counties sustained the greatest degree of injury. Thus, despite the authors' belief that ozone was not responsible for explaining reduced growth rates, the air quality monitoring data for the area and the documented vegetation damage suggest that ozone exposure is a possible cause for reduced growth.

Recently, research performed by Siccama et al. (1981) was cited by Senator Stafford as evidence that the decline of red spruce in the Green Mountains of Vermont could result from acid deposition. The authors, however, conclude that

> The cause of the decline of red spruce is not known. A variety of conflicting hypotheses and observations tend to confuse insights as to possible cause and effect relationships. Current

ideas on causes include 1) climatic change, 2) air pollution-acid rain, heavy metals especially lead, gaseous pollutants, etc.-direct and indirect effects of these and 3) insect and diseases and combinations of these factors as primary and secondary causes.

III. Agricultural Crop Production

Dr. Lance Evans in his testimony stated that studies of the impact of simulated acid precipitation on agricultural crops have produced both positive and negative results. However, it is important to note that most agricultural experts in the country agree that there presently exists no documented evidence that acidic precipitation causes either reduced crop yield or reduced crop marketability. As has been pointed out by the American - Canadian Working Group I (1981), much work is still needed in this very important research area.

IV. Recent Findings

As is evident from the conflicting results outlined above, the working hypotheses must be modified to reflect information which has recently been reported. Some of these modifications are:

1. In the absence of anthropogenic activities, the pH of atmospheric deposition can vary and can include either high or low hydrogen concentration values.

2. Sulfate atmospheric concentrations cannot be used as a surrogate for hydrogen concentrations.

3. Data are insufficient to substantiate the hypothesis that hydrogen ion

concentration trends in both the atmosphere and aquatic environments are evident in the Northeastern United States.

4. Small, high altitude lakes with small watersheds tend to respond quicker to pH changes of incoming water.

V. Conclusion

A refinement of our acidic precipitation effects data base is taking place. Data are being integrated into our current working hypotheses and we are discovering that the resources which may be at risk may be a great deal less widespread than originally perceived. While atmospheric deposition below pH 5.6 is observed in both the northern and southern hemispheres, it is unclear what risks may be associated with the precipitation. Critical scientific knowledge is still being developed to guide those who have to judge whether or not acid rain is, as presently perceived by some, a global problem that must be immediately addressed. Only additional research activities will develop the data that will allow the decision makers to judge for themselves.

I want to thank you for giving me the opportunity to provide the Senate Committee on Environment and Public Works with written testimony. Should you or other Committee members desire further information, I would be pleased to provide it.

Sincerely,

A.S.L. & ASSOCIATES

Allen S. Lefohn, Ph.D.
President

Enclosure: Written Testimony

ASL/res

Comments on the Status of Knowledge Concerning the Effects of Acidic Precipitation on the Aquatic and Terrestrial Ecosystem

I. INTRODUCTION

The past several years have been characterized by widely divergent claims and counterclaims regarding the prospective impacts of acidic precipitation on soils, forests, crops, and aquatic ecosystems. Unfortunately, many of the allegations have been based on conjecture, rather than fact.

There has been a tendency to conclude based on circumstantial evidence that observed biological perturbations are due to acidic precipitation. Furthermore, when observations have not shown effects, it has been suggested that effects do exist and that finer experimental resolution is required to identify harm. In view of the controversy that has characterized the acid rain debate, it is important to carefully examine the current scientific knowledge regarding possible effects. An evaluation of existing data reveals that researchers have been unable to identify whether any significant terrestrial ecosystem impacts have occurred or whether, and if so to what degree, aquatic ecosystem impacts that have been observed result from precipitation acidity.

II. PRECIPITATION pH

One important aspect of the ecological effects issue is the proper departure point in defining the normal pH. Certain scientists have assumed that in the absence of anthropogenic emissions, the normal pH of atmospheric deposition should be 5.6 and that pH values less than 5.6 reflect the occurrence of possible detrimental impacts on the ecosystem that would not occur in the absence of man's influence. Lefohn et al. (1981) pointed out that pH values below 5.6 have been identified in remote parts of the world and that consequently resources should not necessarily be considered at risk from anthropogenic influences when pH values fall below 5.6. Charlson and Rodhe (1982) have confirmed that natural background atmospheric deposition pH values might range from 4.5 to 5.6 due to variability of the sulfur cycle. If the natural part of the atmospheric sulfur cycle is not spatially uniform by as low as a factor of two, then the authors point out that the pH of rainwater unaffected by human activity could be less than 5.0 in some regions. The authors point out that pH can vary beyond the above cited range by simply adding or subtracting the amount of sulfate, ammonium, bicarbonate, or sulfur dioxide in the atmosphere. The authors conclude that

> It is, therefore, not appropriate to use pH equal to 5.6 as a reference value against which human influences should be judged. We believe that pH alone is a poor indicator of departure from the natural composition of rain and cloud water, mainly because of its large natural variability and the difficulty of measuring it accurately. . .

Recently, Sequeira (1982) reported that the pH of atmospheric precipitation at any given location depends upon the chemical nature and relative proportions of acids and bases in solution. The author concluded that a) a pH of 5.6 is not a reasonable reference value for unpolluted or background precipitation; b) relatively lower pH values (e.g., on the order of 4) may not entirely or always be due to anthropogenic acids; c) the recent postulated temporal decrease in precipitation pH in parts of the Eastern United States could be related to decreases in the concentrations of alkaline materials (e.g., Ca^{2+}) in the atmosphere, relative to the acid content; and d) sulfate and nitrate are not reliable indicators of acid deposition unless the relative alkali deposition is negligible, or correlated for neutralization.

III. THE "SULFATE AS A SURROGATE" ASSUMPTION

Many participants in the scientific debate over aquatic ecosystem effects have routinely assumed that sulfate deposition can be used as a parameter for predicting aquatic impacts. In particular, it has been postulated (Working Group I 1981; Loucks et al. 1982) that sulfate atmospheric concentrations can be used as a surrogate for sulfuric acid (H_2SO_4) deposition. If the neutralization process and the deposition of sodium sulfate were negligible, then the hypothesis could be true. However, there does exist a strong correlation between sulfate and alkali/alkaline earth elements in precipitation over the United States (Sequeira 1982). Recent analyses of NADP data reveal that sulfate is highly correlated with sodium along the Eastern and Western coasts. As a result, one should not use atmospheric sulfate as a surrogate for H^+ ion. If this is done, then one over estimates possible environmental impacts.

Other scientists have addressed this issue and have indicated the uncertainty associated with using sulfate as a surrogate. In examining the impact of acid rain on agricultural soils, Coote et al. (1981) have commented on the advisability of using either sulfur or H^+ ion loadings in precipitation for estimating the impact of "acid rain." The authors indicated that "When sulfur alone is used, then the neutrality of calcium, magnesium, sodium and other such salts of sulfur is ignored." While the authors focused on the applicability of using these two chemical forms for predicting possible soil impacts, their comments are relevant to the aquatic ecosystem.

Recent evidence provided by Sequeira (1982) confirms that trouble may arise if sulfate is used as a surrogate for predicting possible acid precipitation effects. Similarly, Peters et al. (1981) observed that changes in sulfate and nitrate concentrations did not correlate with calculated trends in hydrogen ion concentrations. The authors concluded that this observation suggested the variable neutralization of the hydrogen ion.

IV. AQUATIC ECOSYSTEM EFFECTS

Acidified water bodies have been identified in certain areas where acidic deposition has been noted. As a result, the hypothesis has been advanced that these water bodies are necessarily acidic because they have been impacted by the acid deposition, and that any ecological effects that have been observed can be attributed to the acid deposition-induced lake acidity. Although the current data to date cannot substantiate this hypothesis, several researchers have implied that such a relationship does exist. It is, therefore, important to review the evidence that runs counter to the assumption that such a linkage has been established.

A. Anthropogenic and Natural Influences Responsible For Aquatic Ecosystem Impacts

A broad array of natural and anthropogenic influences -- apart from acidification -- may have led to substantial changes in aquatic ecosystems generally, and the Adirondack lakes in particular.

Primarily in Adirondack lakes have losses of fish population (especially brook trout) been attributed to acidifying waters. Retzsch et al. (1982) have suggested possible explanations for several of the observations:

- The presence of extensive, naturally acidic wetlands (fens and bogs) and forest soils either near, or adjacent to, lakes, ponds, and streams.
- Environmental conditions such as low oxygen concentrations, extreme temperatures, high organic and hydrogen sulfide concentrations, and high pollutant (toxic metals and pesticide) concentrations.
- Changes in fish stocking and management efforts.
- Regional development and increased recreational activities.
- Alterations of natural habitats resulting from construction of

dams (man-made or beaver) that manipulate stream flow or lake levels.

The authors state that the headwater lakes in the Adirondacks, which have apparently lost fish populations, are without outlets or inlets. According to the authors, there is a probability that many of the lakes never had indigenous fish populations and that the populations that were present were introduced by man. In many instances, therefore, these populations were maintained principally by annual stocking, since adequate natural reproduction did not occur. Natural reproduction may have been inhibited by limited spawning areas, blockages of spawning routes, or by naturally low pH levels caused by internal biogenic acidification.

Examinations of the past 25 years of stocking data, moreover, indicate that there has been a highly significant decline in numbers of fish stocked in lakes, ponds, and streams within three Adirondack counties sampled. In addition Retzsch et al. (1982) report that the numbers of lakes and ponds stocked also show relatively continuous declines. This decline, according to the authors, is the result of closing to stock waters found to be unsatisfactory for long-term fish survival.

B. Natural Sources of Lake Acidification

In instances where lake acidification has occurred, the influence of anthropogenically produced atmospheric acid deposition may be far less substantial.

1. Terrestrial Ecosystem Generation of Hydrogen Ions

Hydrogen ion inputs in watersheds do not appear to be solely attributable to external (atmospheric) sources. Sollings et al. (1980) demonstrated the importance of internally versus externally generated acid in a H^+ budget calculated for a coniferous watershed in Oregon. The authors determined that the biological processes of vegetative cation exchange and microbial decomposition resulted in a net H^+ flux of about 3000 eq/ha/yr. While the mean H^+ concentration in the precipitation during the study was 6.3 µg/L (pH = 5.2), they hypothesized that an increase in rainfall acidity to pH 4.0 would add only about 10% (300 eq/ha/yr) to the total natural H^+ in the system.

The dominant role played by natural acidic sources, internal to the watershed, in the acidification of surface waters has also been observed by others. Following extensive investigations of the chemical composition of Norwegian soil, Rosenqvist et al. (1980) concluded:

> In . . . Norway, the natural production of acids is many times higher than the acids brought into the area by pollutants. In the Numedal area we have calculated that the atmospheric acids in excess of carbonic acids make up about 5-15% of the total. . . . There is no reason to state that pollutants in modern times are the chief reason for acidification of surface waters.

Recently, Groterdud (1981) has provided additional research supporting the conclusions of Rosenqvist et al. (1980). Measurements were made on microdrainages from lysimeter experiments during heavy rain and snow melt.

Results indicate that the top soil contributed about 4 times the H^+ to the drainage as did the natural precipitation (pH 4.4). The source of H^+ in the top soil is thought to be internal generation. Further indication that budgets of H^+ in watersheds dominated by internal watershed factors is provided by published results from the Hubbard Brook experiments. According to Likens et al. (1977), the internal supply rate of H^+ to Hubbard Brook equals the external supply, and suggests that "external and internal generation of H^+ ions play nearly equal roles. . ."

2. Aquatic Wetlands Production of Hydrogen Ions

Surface water acidification can result from natural processes internal to lakes. In particular, changes in lake pH may stem from the drainage of acidic waters from bogs into poorly buffered lakes. Bogs can have pH values in the range 3.2-3.8 (Buckman and Brady 1960; Hutchinson 1957) and sphagna in such wetlands --- common throughout the Adirondacks -- can "increase acidity by releasing hydrogen ions in exchange for dissolved cations such as calcium, magnesium, sodium and potassium." (Andrus 1980). Wetzel (1975) has confirmed the importance of wetlands and in particular, Sphagna:

> In large areas of sedimentary rock that have been glaciated, it is common to find former marl lakes overlain by bog lakes and bogs. . . The subsequent vegetative development then can proceed relatively rapidly, in a rather classical pattern of bog succession from a lake to a terrestrial situation, by accelerated accumulation of organic matter under acidic, reducing conditions that are not particularly favorable to decomposition.

3. Acidification Resulting From Shifts in Land Use

Forest ecosystem disturbances can result in temporary increases of pH, followed by decreases in pH once the forest has become reestablished. An examination of plankton remains in sediment cores from Lac Laflamme, Quebec, indicated that the aquatic pH had historically remained about 5 until the late 1800's (Brakke 1981).

C. Historical Lake pH and Recent Acidification Trends

Certain observers have advanced the theory that 1) lake acidification is a relatively recent phenomenon and that 2) lakes have become increasingly acidic in recent years.

It is important to recognize, however, that some lakes have been subjected to acidic influences for thousands of years. Using assemblages of diatoms and other groups of organisms found at current pH levels in surface waters, regression models have been developed. These models have been used to estimate historical pH levels for surface waters, using remains from biotic assemblages found in benthic sediments. While some may question the use of such paleolimnological methods to predict historical pH levels, application of diatom models to modern diatom assemblages have yielded successful predictions of modern surface water pH levels (Whitehead et al. 1981). These models and the paleolimnological evidence on which they are based, lead one to conclude that natural acidification processes have been acidifying lakes for the past 10,000 years. This acidification is correlated to the development of coniferous forests within the surrounding watershed; similar forests are found surrounding many of those lakes reported to be currently undergoing acidification.

Whitehead et al. (1981) have investigated 37 Adirondack Lakes, using methods devised to estimate historical lake pH levels from assemblages of diatoms in Sediment cores. All lakes were found to have been basic in the Late Glacial Era (pH 7.0 -8.0) and to have become markedly more acid during the Early Holocene (generally, pH 6.0). Some lakes have had a pH level of 5.0 for the past 2,000 to 10,000 years. It was hypothesized that historic depressions of pH levels were related to changes in terrestrial vegetation and resulting soil pH depressions. Core pollen analyses indicated the pH levels decreased in the lakes concurrent with the movement of hemlock and fir into the watersheds.

Ford (1981) investigated cores from South King Pond in Vermont, and Cone Pond, a soft water New Hampshire pond. Diatom analyses also indicated that Cone Pond has been acidic for most of the past 10,000 years. Further analyses indicated that the concentration of $CaCO_3$ (alkalinity) in South King Pond declined to nearly zero about 5,000 years ago. Pollen analyses indicated that spruce arrived at the watersheds of both ponds about 2000 years ago; diatom analyses indicated that the pH levels in both ponds decreased.

The second element of the "trends" issue -- the question of whether aquatic ecosystems in the Eastern North America are acidifying -- can best be addressed by looking at trends in surface water pH. A variety of studies have been performed that may shed light on recent trends. One of these studies, performed at the Hubbard Brook Experimental Forest in New Hampshire, provides the longest continuous record of precipitation and stream chemistry in North America (Likens et al. 1977). These data demonstrate no clear trends in the pH of precipitation or streams from 1964 to 1974.

The United States-Canadian Impact Assessment Workgroup (Working Group I 1981) has suggested that data derived from Hendrey et al. (1980), appear to demonstrate a slight decrease in the pH of some North Carolina streams, when comparing the period 1960-1963 to 1979. However, the pH values reported for the period 1960-1963 were measured using colorimetric techniques -- a method that tends to yield spurious or under estimated H^+ readings in low conductivity and poorly buffered water (Hendrey et al. 1980). Since the waters measured in North Carolina exhibit such characteristics and therefore, the apparent trend of decreasing pH may be spurious, presenting an inaccurate account of actual aquatic conditions.

It is important to put the results of Hendrey et al. (1980) in perspective by reviewing the article of Powers (1929). In 1925 and 1926, the author surveyed the water quality of numerous streams of the Great Smoky Mountains National Park. The pH values (measured colorimetrically) varied from 4.1 to 6.4. These waters all exhibited low alkalinities. The fact that the colorimetric method was used suggests that the measured pH values were greater than the actual values (Pfeiffer and Festa 1980). Powers (1929) found that even the most acidic streams (pH 4.1) contained good populations of brook and rainbow trout. Both pH and alkalinity were found to decrease with increasing altitude. Moderate to large increases in stream flows from precipitation caused increases in the H^+ ion concentration and decreases in alkalinity in the lower elevation portions of the streams. Thus, depressions in stream pH noted by Hendrey et al. (1980) could possibly represent natural, historical conditions rather than an effect of precipitation with recently increased acidity.

A.H. Johnson (1979) has hypothesized that a decline of approximately 0.4 pH units over the last twenty years in two headwater streams in the Pine Barrens of New Jersey took place as a result of atmospheric deposition. The author's analysis showed a statistically significant correlation coefficient with a negative slope (i.e., decreasing pH with increasing time). However, the analysis failed to take into consideration the confidence interval for the slope. As described by Draper and Smith (1981), the confidence interval about the slope is determined by the square root of the slope's variance and the student-t value. The magnitude of the slope's variance is a function of the regression analysis's coefficient of determination (r^2). Thus, one would expect a large confidence interval around the slope if the r^2 were small. The highest coefficient of determination that the author reported was 0.31. This low value implies that the confidence interval around the slope is great and it may be possible that the calculated negative time slope may, in fact, be closer to zero than originally anticipated.

It has been noted by other investigators that there is, at present, no indication of any adverse effects on the aquatic life of the lakes of the region from acidification (Patrick et al. 1981). Many streams of the Pine Barrens are naturally acidic (pH 4-5) and some lakes in the region are experiencing increases in pH as a result of eutrophication (Patrick et al. 1981).

A survey of Pennsylvania streams was conducted by Arnold et al. (1980) to identify if acidic precipitation were impacting the aquatic ecosystem. The authors' analyses included only extant data from those streams surveyed at least twice, one year apart, and only those showing decreases in pH or alkalinity. A decrease in pH, alkalinity, or both was found in 40% of all surveyed streams with a mean decrease of 0.37 pH units. Although not reported, it must be assumed that 60% of the streams showed no change or showed an increase in pH and alkalinity. Since no effort was made to standardize the daily or annual sampling times, finding 40% of all streams with such a decrease in pH or alkalinity is not unusual. Such data can easily be attributed to annual or diurnal variations in pH and to analytical error. Annual and diurnal variations of 1-2 pH units are common in poorly buffered waters (Allen 1972; Juday et al. 1924). Because Arnold et al.'s (1980) survey was biased toward waters having decreases in pH, while ignoring waters with no changes and those with increases, these results cannot be applied when determining regional time-trends in surface water acidity.

Recently, Bailey et al. (1981) performed a comprehensive analysis of time-trend lake pH data. The analysis included only lakes for which at least nine years of continuous pH measurements were available (at least one data point per year). One hundred seventy-eight such lakes were identified and analyzed. Of these, 62 showed that alkalinity increased with time and 12 showed that acidity has increased with time. Of the total, 104 sites showed no significant trend. The preliminary results suggest that the acidity of lakes is not changing in the areas surveyed (i.e., in the Northeast, Midwest, Florida, or nationally). Because of the remoteness of the higher elevation, shallower, poorly buffered lake systems, there is no data base that is adequately continuous to allow analysis. Therefore, the implications from this study are that the suspected impact from atmospheric deposition on surface waters is not as widespread as previously believed.

Work by Peters et al. (1981) provide some interesting results. The authors reported that statistical analyses of chemical data from several streams throughout New York yielded little evidence of temporal trends resulting from acidic precipitation, except in the Adirondack mountains.

D. Suspected Aquatic Ecosystem Impacts

It has been hypothesized that some observed alterations in biotic components could be a result of atmospheric deposition from long-range transport processes. Some of the data most often cited to support this inference is from Sudbury, Ontario. Documented cases of fish losses from the

Sudbury, Ontario area are apparently due to the direct result of impacts from the Sudbury base-metal smelting operations. These operations may be the largest point source of atmospheric sulfur in the world (Beamish 1976).

E. Aquatic Ecosystem Chemistry Modeling

Two principal models have been used to predict sulfate loading rates necessary to protect surface waters from atmospheric deposition. All of the models implicitly assume that 1) atmospheric deposition has become more acidic in recent times, and that 2) surface waters are primarily acidified from atmospheric deposition rather than from acid sources internal to the watershed and the water bodies. The models also fail to recognize that H^+ involved in acidification can be associated with anions other than SO_4^{2-}, as previously noted by Lefohn et al. (1981).

Both the Almer/Dickson Relationship and the Henriksen Nomograph were developed using European data. The Almer/Dickson Relationship is based on Dickson's observation that Swedish lakes showed typical acid-base titration curves when excess sulfur lake influxes were plotted against pH inputs (Almer et al. 1978). Thus the model is only designed to relate sulfur in lakes with aquatic pH. The Almer Dickson Relationship has been misinterpreted by Working Group I (Working Group I 1981) as establishing a relationship between atmospheric sulfate loadings and aquatic pH.

In the original paper by Almer et al. (1978), the authors simply compared several lakes with varying sulfur loadings in different parts of Sweden to their present pH and sulfur influxes. The authors concluded that these lakes -- the most sensitive ones that can be found in Sweden -- may resist a load of about 0.3 g S/m^2 lake water each year. Thus, the x axis used by Almer et al. (1978) is labeled "Excess S in lake water g/m /year." It appears that the authors of Working Group I have misinterpreted this label and have confused it with atmospheric deposition. The two are distinctly different. Thus, the Almer/Dickson model cannot predict an atmospheric sulfate loading value unless a direct correlation exists between atmospheric sulfate deposition and the sulfate concentration found in lakes and streams. No such link has been established.

Henriksen (1980) presents a nomographic model for lake acidification, relating stages of acidification to pH levels of precipitation within sensitive regions of Norway. Working Group I suggests permissible maximum lake water sulfate concentrations based on Ca^{2+} or Ca^{2+} + Mg^{2+} concentrations.

As a test of the Henriksen Nomograph, Wright et al. (1980) plotted additional sets of data. For Norway and Scotland, the nomograph appeared to adequately predict lake pH concentration. However, when data from the Adirondacks and Sudbury were added, actual pH values for the lakes deviated from predicted values.

Henriksen has acknowledged that a serious problem with his model is the ". . . assumption that Ca and Mg neither decrease nor increase significantly in response to acidification" (Henriksen 1980). Henriksen noted, moreover, that calcium concentrations have increased with surface water acidification. Increased cation concentration (including Ca and Mg) in surface waters is a basic premise of aquatic models under consideration (Working Group I 1981). Thus, this assumption appears to require further verification prior to the model's application.

F. Conclusion

The state of knowledge concerning the relationship among atmospheric SO_4^{2-} concentrations, lake acidification, and fish populations (and other aquatic organisms) in the surface waters of North America, is limited. In virtually all regions having acid precipitation, some poorly-buffered lakes maintain healthy fish communities. Thus, the cause and effect relationships between levels of sulfate in precipitation and effects on aquatic organism communities have yet to be adequately investigated and at this time provide little insight into identifying possible biological mechanisms.

V. TERRESTRIAL ECOSYSTEM EFFECTS

There have been several attempts made to define the relationship between forest productivity and acidic precipitation (Jonsson and Sundberg 1972; Jonsson 1977; Abrahamsen et al. 1977). As pointed out in the Working Group I

Interim Report (October 1981), no documented, scientific, field validated evidence exists for showing a direct effect of acidic precipitation on forest productivity. Abrahamsen et al. (1977) were not able to confirm the initial interpretation by Jonsson and Sundberg (1972) that a statistically significant difference existed for relating growth trends and annual tree ring development to the level of acidic precipitation. Abrahamsen et al. (1977) concluded that, "No effect that can be related to acid precipitation has yet been detected on diameter growth."

Additional growth reduction parameters were calculated for a number of geographic locations and plotted on a map by Strand (1980a, 1980b). This pattern was compared with a corresponding pattern of SO_2 or pH in precipitation. The geographical pattern showed some similarity with the geographical pattern of the deposition of average sulfur pH of the precipitation, but also some differences. Strand concluded that with this kind of data sample over large areas -- with limited information on stand history and change in soil and geographical conditions -- the effect must be at least 1% per annum to be detected. As noted previously, it has not been possible, utilizing his method of tree ring analysis, to find definite evidence that acid precipitation has had an effect on the growth of trees.

In the United States, Cogbill (1976) initiated a tree ring investigation dealing with acidic deposition effects. Tree borings taken in 1972 at an aged, minimally disturbed, mature hardwood stand located in New Hampshire, and in 1973 at a spruce-fir stand in Tennessee, were analyzed for yearly increments over the past 100 years. According to Cogbill (1976), the tree-ring chronologies for the 18 American Beech, 23 birch, and 16 sugar maple trees sampled in New Hampshire did not show any consistent trends. Significant declines in the beech incremental growth were observed between 1940 and 1970, but not between 1950 and 1970. Birch growth showed significant increases in growth for the same two periods, while the maples showed irregular growth patterns. Basal area growth patterns for these same hardwoods showed a general increase with time, but with more pronounced fluctuations during the most recent 50 years.

Cogbill's examination of increment cores from 31 red spruce in Great Smoky Mountains National Park revealed irregular decreasing growth which was significantly different from the steady growth at the 5% level for the 1910-1970, 1940-1970, and 1950-1970 periods. However, application of multiple linear regression techniques showed that after the effects of weather variables were included, no residual downward growth trend could be detected at either site. Cogbill concluded from his investigation that no regional, synchronized decrease in radial increment growth was evident, nor were the growth patterns in Tennessee and New Hampshire dissimilar, despite greater assumed deposition in New Hampshire. Cogbill further concluded that a correlation of forest growth with acid precipitation in Eastern North America could not be established at the present time due to 1) the large variance of tree growth estimates with no breakpoints, and 2) the unknown initiation date of acid precipitation (Cogbill 1976).

A.H. Johnson et al. (1981) have been cited as providing evidence that acidic precipitation has had an effect on a forest ecosystem in the New Jersey Pine Barrens area. The statistical analysis has generated a mathematical model that does not fit well with the reported data. The authors have attempted to correlate 1) stream pH with precipitation pH and 2) an abnormal decrease in growth of pitch pine with stream pH. The statistical analysis shows a highly significant correlation coefficient (r) value of 0.44, but a coefficient of determination of 0.19. This indicates that the mathematical model selected by the authors does not fit well with the reported data. The coefficient of determination reported indicates that approximately 81% of the variability is not explained in the model that describes stream pH and the precipitation and that the variability is due to other factors not included in the hypothesized linear model. Thus, with the great amount of uncertainty associated with the mathematical model, one is led to the conclusion that 1) the proposed model does not adequate describe the desired mathematical relationship and 2) stream pH has not been shown to be a reliable index of precipitation pH.

A.H. Johnson et al. continued their discussion by attempting to explain an abnormal decrease in growth of pitch pine by mathematically correlating this decrease with stream pH. The statistical analysis showed a significant correlation between stream pH and growth. However, care must be given for the consideration that stream pH may be correlated with other environmental variables. For example, Likens et al. (1977) reported that stream pH was a predictable function of stream flow. The authors found increasing stream flow increased H^+ ion concentrations. Thus, a possible strong link may exist between the internal generation of hydrogen ions and precipitation. It is this link that may result in increased stream pH when precipitation increases.

One of the major unexplained concerns in the New Jersey Pine Barrens is the reduced growth rate. The authors did investigate possible causes for decreased growth rate. They felt that the effects of pests were absent, as were effects of wildfire. Retention in appearance of needles was normal, and the authors believe that ozone did not cause damage.

However, when one reviews the ozone ambient air quality for the Pine Barren area, it is evident that the ozone levels are of sufficient quantity to cause injury and or damage. Feliciano (1972) and Pell (1973) reported air pollution damage to several counties near the New Jersey Pine Barrens area. A survey of injury resulting from air pollution episodes and assessment of their resultant effect on crop production in 1971 was conducted. Economic loss of crops due to air pollution was estimated at $1,183,800. Over one-fourth of the total crop losses were recorded in Cumberland County. Other counties where damages exceeded $100,000 were Burlington, Atlantic, and Salem. Feliciano (1972) attributed photochemical oxidant to 80 percent of the plant injury recorded. Pell (1973) reported that the total losses to crops in 1972 was $128,019. Forty-seven percent of the plant damage was caused by oxidants. Cumberland, Warren, Atlantic and Salem Counties sustained the greatest degree of damage.

A.H. Johnson et al. stated that no significant relationship existed at the

5% level between ozone and growth. It is unclear what mathematical indices were used to describe ambient zone exposures. Oshima (1974) and Heagle et al. (1979) have described different indices that are useful in projecting ozone damage. It is possible that the authors failed to observe a statistical relationship between ozone exposures and growth because they selected an incorrect ozone exposure index. Thus, while the authors believe that ozone was not responsible for explaining reduced growth rates, the air quality monitoring data for the area and the documented vegetation damage tend to lend credance to ozone as a possible cause for reduced growth.

The work of Raynal et al. (1980) has recently been characterized as offering preliminary evidence in support of claims that acid precipitation has resulted in forest impacts. The authors identified several important ecosystem components and analyzed the components' sensitivity to acidic precipitation through field and laboratory documentation and experimentation. Forest soils, vegetation, microorganisms, and tree disease were the major aspects considered in their investigation.

In contrast to the findings of Cogbill (1975a, 1975b), the authors found changes in growth of red spruce and white pine following 1965 that were not attributable to climatic variation or successional trends. However, due to the complexity of the forest ecosystem, the authors stated that it was not possible to attribute the observed growth changes directly to acid precipitation effects. The authors concluded by stating that, "dendrochronological methodology is not likely to produce conclusive evidence regarding tree response to acid precipitation because numerous unmeasured interacting abiotic and biotic factors simultaneously regulate tree growth."

Recently, research performed by Siccama et al. (1981) has been cited as evidence for the decline of red spruce in the Green Mountains of Vermont. While this report has been used by some investigators to infer that the authors' results illustrate a tie between acidic deposition and the decline of red spruce, the authors actually conclude something entirely different. Siccama et al. (1981) state

> The cause of the decline of red spruce is not known. A variety of conflicting hypotheses and observations tend to confuse insights as to possible cause and effect relationships. Current ideas on causes include 1) climatic change, 2) air pollution-acid rain, heavy metals especially lead, gaseous pollutants, etc.-direct and indirect effects of these and 3) insect and diseases and combinations of these factors as primary and secondary causes.

As pointed out in Section IV, Rosenqvist et al. (1980) note that in areas where industrial pollution is moderate (for instance, in Norway) the natural production of acids is many times higher than the acids brought into the area by pollutants. In the Neumedal area, the authors calculated that the atmospheric acids in excess of carbonic acids make up about 5-15% of the total. There are large fluctuations in the natural acid production due to the climatic and biological changes. The authors believe that there is no reason to conclude that pollutants in modern times are the chief reason for the acidification of surface waters.

In areas at high altitude and with a fairly high percentage of exposed rock (as in the upper Neumendal Catchment), natural H^+ ion production is of the order of magnitude 200-500 meq/m^2/yr and the anthropogenic airborne acidity is of the order of 20-50 meq/m^2/yr (Rosenqvist et al. 1980). The authors stated that a minor part (approximately 20%) of the available protons are mobilized in ion exchange and weathering. The anthropogenic sources of H^+ are thought to play a minor role in the total production of H^+ in the terrestrial ecosystem.

While results to date do not support claims that acidic precipitation has caused damage to the forest ecosystem, the fact does remain that acid rain or any other chemical input (including water, itself) in sufficient quantities could eventually harm forests. The key factors are 1) the amount of input (as moderate inputs may be beneficial to forests deficient in sulfur and nitrogen) and 2) the characteristics of the site receiving the chemical input. Recent Norwegian studies demonstrate the ability of those forest ecosystems to tolerate acid inputs and aluminum levels. An intensive series of irrigation studies in the field was performed. The study involved the input of sulfuric acid ranging from control or current background levels (approximately 0.8 keq/ha/yr) to approximately 30 times that amount (approximately 26 keq/ha/yr). These inputs were applied to four tree species (Scots pine, lodgepole pine, Norway spruce, and birch) at two major sites--Amli and Nordmoen. At Amli, both mature and sapling Scots pine stands were irrigated, and in all other cases, young plantations were irrigated. Irrigation treatments were combined with liming at three levels (500, 1500, and 4500 kg/ha as CaO). Full details for this experiment are described by Abrahamsen (1980a, 1980b).

Of particular interest in the series of experiments were concentrations of aluminum and soil solutions from monolith lysimeters, which reached 60 ppm (Abrahamsen 1980a, 1980c). Trees growing on the same soil experienced no apparent negative effects, irrespective of the tree species tested. It should be noted that annual acid inputs in these studies equaled 10-30 times those received at Solling, Germany (700 eq/ha/yr), and total acid inputs over the 7-year irrigation period equaled about 60 years worth of current input beneath the spruce stand at Solling (3000 eq/ha/yr) and 120 years worth of current input beneath the beech stand at Solling (1520 eq/ha/yr). The extremely high inputs of acid to these Norwegian forests (which increased the Al concentration in soil solution) have not yet produced serious effects.

Ogner and Teigen (1981) found that acid irrigation causes increased growth at 12 degrees C, but causes some damage from acid irrigation and death at 24 degrees C. The authors concluded that Norway spruce has great capacities to tolerate extreme acid inputs at field temperatures in Norway.

The Norwegian studies have contributed a great deal to the debate by illustrating that large quantities of sulfate and aluminum did not cause serious damage to the forest ecosystem at the specific sites monitored.

B. Crops

Simulated acid precipitation experimental studies on agricultural crops have produced positive, negative, and no effects (Lefohn et al. 1981; Jacobson 1980; and Shriner 1978). These experiments are performed indoors, either in greenhouses or in controlled environmental chambers, or outdoors under conditions that approximate those occurring on commercial farms. Attempts to compare and interpret the results are difficult, since different procedures and techniques have been employed by laboratories throughout the United States.

Research is continuing across the nation on the effects of acidic precipitation on field grown crops at the Argonne and Brookhaven National Laboratories, the Boyce Thompson Institute, North Carolina State University, and Oregon State University. Increases and decreases in yield, as well as no significant effects, have been found, depending on concentrations of acids, plant species and cultivars, pattern and timing of rain applications, and soil, environmental, and cultural conditions (Irving and Miller 1980; Lee et al. 1980). As has been pointed out by the Working Group I (1981), direct effects on plants exposed to higher than normal H^+ ion concentrations have not been documented in the field. Further work is still needed in this very important research area.

Recent concern has been expressed by some scientists about the possible effects on crops from simultaneous exposures of ozone and acid precipitation. Preliminary results by Jacobson et al. (1980), Troiano et al. (1981a, 1981b) show that under simulated acid rain and filtered and non-filtered ambient oxidant conditions, ozone and acid rain tended to show interactive effects. While the results are preliminary in nature, they do point to the fact that further research is needed to determine if acid precipitation enhances the likelihood of actual yield reductions in areas also experiencing repeated exposures to elevated exposure of ozone. The difficulty in properly addressing the possible combined effects of the two pollutants is complicated by the uncertainty surrounding the level of acidic precipitation dose that should be administered. If one is unable to adequately describe acidic precipitation exposures as a function of concentration, frequency, and duration, it may be difficult to integrate the possible synergistic effects of ozone into a comprehensive research program.

VI. The "Resources at Risk" Concept

Recently the U.S.-Canadian Impact Assessment Working Group (Work Group I 1981) introduced the concept of "resources at risk." The approach utilizes subjective criteria to identify aquatic and terrestrial resources that are potentially susceptible to a pollutant source (e.g., acidic precipitation).

There are a series of concerns associated with the approach. First, the criteria relied upon may not accurately assess the probability of harm. Second, and more fundamentally, the approach is premised upon speculation, not fact. At best, the resources at risk approach can only be used to refine research experimentation and not to develop policy initiatives.

For example, a report that has received considerable attention over the past few weeks has been prepared by Loucks et al. (1982). The report concludes that there may be an increase of 4% to 15% more lakes either becoming "acidified" or "extremely sensitive" to acid inputs by the year 2000. Under a slightly different scenario, the authors estimate that by decreasing sulfate deposition by 20% by the year 2000 will cause recovery of 10-25% of the most sensitive lakes and streams. It is further estimated that a 35% decrease in sulfate deposition by the year 2000 will result in a 16-41% recovery for the most sensitive aquatic resources.

The authors have assumed that 1) aquatic resources at risk can be solely based on using "alkalinity" as an indicator for sensitivity and 2) the amount of sulfate in the atmosphere can be used to predict the amount of hydrogen that will be available to titrate the soil and aquatic components of the environment. As has been discussed above, several authors believe that sulfate cannot be used as a surrogate for the hydrogen ion. Based on my review of these scientific articles and the current NADP data base, I believe the Loucks et al. (1982) report findings cannot be used to predict possible changes to the existing status of aquatic resources

The first assumption by Loucks et al. (1982) that alkalinity can be used as the key indicator for predicting aquatic sensitivity, I find to be too simplifying. The aquatic ecosystem is a complex system which defies simple models. A complex set of factors is involved in determining the potential susceptibility of surface waters' sensitivity of acidification. These factors involve characteristics of both the watershed and the water bodies. Important watershed factors include 1) soil chemistry, 2) soil particle size, 3) soil texture, 4) ionic adsorption capacity, 5) soil depth, 6) bedrock geology, 7) soil drainage, 8) land form relief, and 9) terrestrial vegetation cover (Cowell et al. 1981). For surface waters, the buffering capabilities principally relate to dissolved alkalinity levels, sediment bicarbonates, weak organic acid content, sulfate reductions, surface area, water volume, flushing rates, biological activities, and trophic level (Schindler et al. 1980; Eilers and Webster 1981). Despite the complexity of factors necessary for the analysis of ecosystem sensitivity, only a few, narrowly defined criteria have been applied by Loucks et al. The application of lake alkalinity levels as an indicator of susceptibility is too limiting and may over state the resources that actually are at risk.

VII. GENERAL CONCLUSIONS

Considerable research efforts have been devoted to gathering data which will help examine possible acidic precipitation effects. Working Group I as well as other organizations have worked to define the current state of knowledge. Unfortunately, however, one clear trend has appeared. Most, if not all, of the summary reports on possible acid rain effects have failed to explain that statements made concerning effects often represent working hypotheses under which research scientists are presently operating. As a result, most summaries suffer from a failure to separate fact from conjecture. This inherent weakness has resulted in scientific data being stretched beyond their intended use.

Questions remain concerning what research still needs to be done before we can intelligently analyze the impact of acid deposition. The following fundamental questions still need to be answered:

1. What will happen if the amount of acid deposition is changed?

2. How many lakes are in capable of supporting fish because of acid deposition?

3. How many lakes will become supportive of fish if acid deposition can be reduced.

4. What other remedial measures (or combinations of measures) will make a lake supportive of fish?

5. Are forests and soils impacted by acidic deposition?

6. Are agricultural crops affected by acidic deposition?

7. Are agricultural crops affected by a synergistic relationship between ozone and acidic deposition?

The foregoing testimony devotes a considerable amount of time attempting to document what is and what is not known about the effects of acidic deposition on the environment. While certain of my colleagues may believe that we do know enough to recommend action, the current state of knowledge shows that we are presently working under a set of hypotheses which may or may not be correct. As has been adequately stated by Glass and Brydges (1981),

> Advances in scientific knowledge are always uncertain without the development and subsequent testing of scientific hypotheses. No hypothesis can ever be 'proven', however; natural science advances by observation, first, and by 'failing to reject' hypotheses in more systematic experimental work...Scientists usually require that many more tests of an hypothesis be undertaken before it has substantial credance, but there is no consensus as to how much testing is needed before it is given the status of a 'reasonably established' explanation...We also recognize the difficulty in trying to draw conclusions when the most important hypotheses are at a point where current tests fail to reject them outright, but more tests are needed before all scientists accept the explanations--if that is possible.

The purpose of submitting my testimony to this committee is to provide its members with a clear statement of the uncertainties associated with those hypotheses that have been identified as descriptive of the possible ecological impacts associated with atmospheric acidic deposition. Simply stated, I believe the existing base of acid rain knowledge does not support the claims by some that "we know enough." Critical scientific knowledge is still being developed to guide those who have to judge whether or not acid rain is, as presently perceived by some to be, a global problem that must be immediately addressed. To many of us who have reviewed the state of world-wide knowledge, we believe the jury is still out.

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THE EFFECTS OF ACID RAIN CONTROL MEASURES ON THE COAL MARKET

EXECUTIVE SUMMARY

As part of an assessment on transported air pollutants, OTA has prepared this report on the effects of acid rain control legislation on coal markets and coal-related employment. Other issues, for example the costs to utilities of sulfur dioxide emissions reductions and the effects of transported air pollutants on natural resources, will be discussed in the full assessment.

S.1 INTRODUCTION

Many legislative proposals for controlling acid rain have focused on reducing sulfur dioxide emissions in the eastern United States. Sulfur dioxide is formed when sulfur, an element naturally present in fossil fuels, is "oxidized" during the combustion process. The greater the concentration of sulfur in the fuel being burned, the greater the production of sulfur dioxide gas. Consequently, switching from high- to low-sulfur coal is one way to achieve substantial emissions reductions.

By significantly increasing the value of low-sulfur coals relative to high-sulfur coals, emissions reductions designed to control acid rain could potentially cause significant coal-market shifts. Because the sulfur content of coal varies significantly from region to region throughout the United States, any emissions reduction strategy that relies even in part on "switching" to lower-sulfur coals can potentially affect the regional distribution of coal production and employment. This analysis assesses the potential direction and magnitude of these effects due to regulations designed to control acid rain.

S.2 FINDINGS

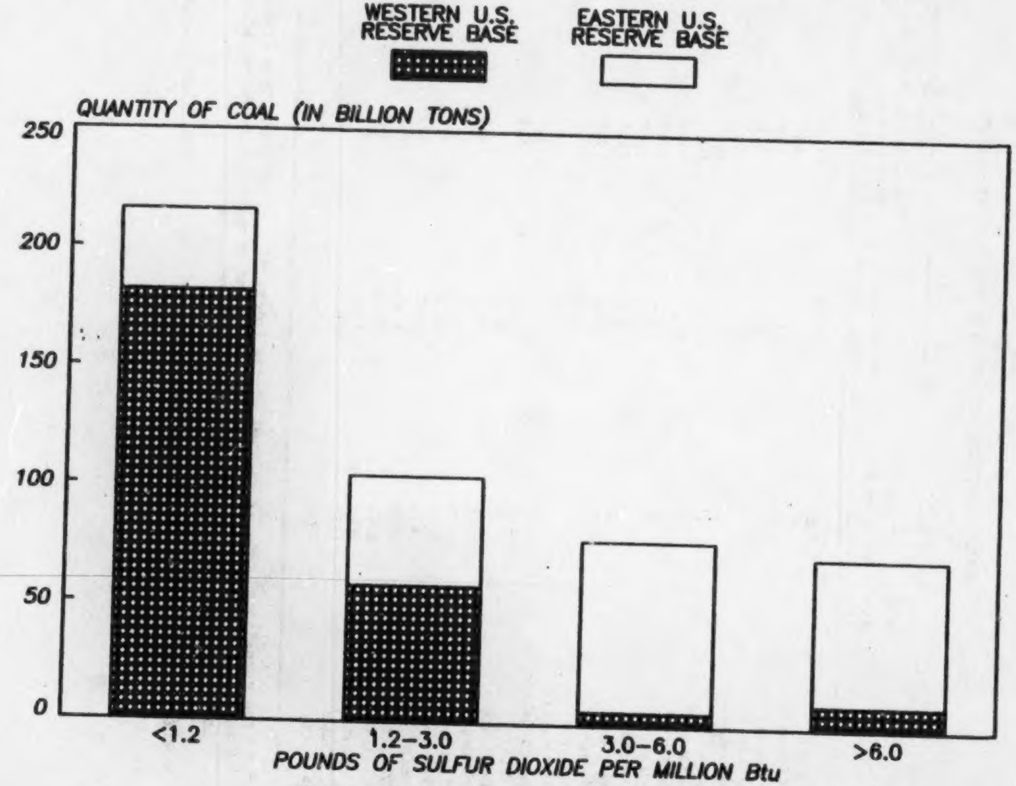
A. Factors Contributing to Potential Coal Market Shifts

The regional character of the potential coal-market effects due to changes in sulfur dioxide emissions requirements stems from the variations in the sulfur content of coal among various geographical areas of the United States. Figure S.1 shows the distribution of the sulfur content of coal reserves for the eastern and western United States. Western reserves are primarily low-sulfur, while reserves in states east of the Mississippi are primarily high in sulfur. The exceptions to this pattern are the states of Kentucky and West Virginia, which contain significant quantities of low-sulfur reserves.

Table S.1 presents each state's coal production for the utility market. The first column presents the quantity of coal, in millions of tons, produced for the utility market by each state in 1980. The second column shows the percentage of that production that would not permit utilities to comply with a 1.2 pounds of sulfur dioxide per million Btu emissions limit without applying control technologies. The third column presents the portion of this "non-compliance" coal that is sold on the spot market, i.e., is not covered by a contract between a utility and a mining company. Non-compliance coal sold on the spot market is likely to be the most vulnerable to more stringent sulfur dioxide regulations. The final column shows the portion of non-compliance coal that is exported to other states — an indicator of the potential efficacy of state-level policies to minimize coal market disruptions.

FIGURE 8-1

DEMONSTRATED RESERVE BASE BY SULFUR CATEGORY



OFFICE OF TECHNOLOGY ASSESSMENT, PECHAN & ASSOC., 1982

TABLE S.1

COAL PRODUCTION FOR THE DOMESTIC UTILITY MARKET

	1980 Production for the Utility Market (millions of tons)	Percentage Non-Compliance*	Percentage Non-Compliance Sold on the Spot Market	Percentage Non-Compliance Exported to Other States
Alabama	15.8	82.5%	17.3%	10.1%
Arizona	10.5	0.0	0.0	0.0
Colorado	13.6	7.1	0.4	2.8
Illinois	53.4	99.9	6.6	66.0
Indiana	27.3	99.9	8.3	22.1
Iowa	0.4	95.9	14.5	0.0
Kansas	0.7	100.0	29.3	81.7
Kentucky	112.4	89.9	16.5	72.9
East	73.9	83.2	19.0	75.1
West	38.5	100.0	11.8	68.7
Maryland	1.2	100.0	22.8	24.7
Missouri	5.0	100.0	6.9	33.5
Montana	27.9	63.6	0.0	51.9
New Mexico	17.0	69.8	0.3	1.2
North Dakota	15.3	99.2	13.6	20.8
Ohio	34.3	100.0	18.9	26.5
Oklahoma	2.7	98.6	17.3	98.6
Pennsylvania	50.9	99.1	29.9	30.[illegible]
Tennessee	7.6	86.7	17.6	34.6
Texas	27.0	100.0	0.0	0.0
Utah	8.5	20.0	1.1	7.1
Virginia	13.8	87.5	10.6	71.0
West Virginia	53.1	81.3	8.1	39.4
North	30.8	97.8	7.5	46.1
South	22.3	58.5	8.8	30.1
Wyoming	89.7	16.6	0.9	9.9

* "Non-compliance" coal is defined as the amount of coal produced by a state that would not permit utilities to comply with a 2 pound of sulfur dioxide per million Btu emissions limit without applying control technologies.

SOURCE: From DOE/ETA Form 423 data, supplied to OTA by E.H. Pechan and Associates.

B. Summary of Regional Analysis: Projected Patterns of Change

There is a great deal of uncertainty about how large the impacts of acid rain controls on the coal-market might be. The magnitude of impact depends on the amount of emissions reductions required and the manner in which those reductions are achieved. OTA bases its estimates on results of a computer model that projects changes in regional coal production due to sulfur dioxide emissions reductions of 5, 10, and 13 million tons.[*] The model used, developed by ICF, Inc.,[**] calculates the emissions reduction strategy that minimizes costs to the utility industry. These model-based estimates are highly dependent on model assumptions of the costs of alternative emission control approaches, projections of electricity growth, and other factors. OTA has combined ICF production projections with coal-miner productivity and income data to project the employment and economic effects of acid rain controls.

Several generalizations emerge from a review of the ICF model results. First, national coal production is projected to increase significantly by 1990. Second, regulations designed to control acid rain, even those calling for the largest emissions reductions, do not alter these projected increases at the national level. However, even though acid rain control measures are not projected to produce changes in nationwide coal production, the model projects a redistribution of production among regions.

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[*] In 1980 the electric utility industry in the eastern U.S. emitted 16 million tons of sulfur dioxide. Total emissions of sulfur dioxide in this region were 22.5 million tons.

[**] The ICF Coal and Electric Utilities Model has been modified from the DOE National Coal Model. The ICF model has been used to project the effects of acid rain control proposals by: the Environmental Protection Agency, the Department of Energy, the National Wildlife Federation and National Clean Air Coalition, and the Edison Electric Institute. The model results presented here were not performed by ICF for OTA, but for the other groups mentioned above.

Table S-2 presents the effects of acid rain control measures on regional coal production. For the high-sulfur coal areas of the Midwest (Illinois, Indiana, and Western Kentucky) and Northern Appalachia (Pennsylvania, Ohio, and Northern West Virginia), 1990 coal production is projected to be less than it would have been in 1990 without acid rain controls for all emissions reduction scenarios. For emissions reductions of 10 million tons and greater, production in these areas is projected to decline to about 10 to 20 percent below 1979 levels. Estimates of production declines are averaged over these regions, and thus may be greater or less in some states and counties than others.

For the low-sulfur coal areas of Central Appalachia (Eastern Kentucky, Southern West Virginia, Tennessee, and Virginia) and the Western U.S., acid rain control measures are projected to expand coal production beyond what 1990 levels would be assuming no change in regulations. This effect is more pronounced in Central Appalachia than in the West, due to its proximity to eastern markets.

Employment changes in general are projected to follow changes in production. However, the uncertainty regarding future coal-miner productivity trends serves to create a larger band of uncertainty for employment effects than for production.* Table S-3 displays projected effects on the coal-mine labor force of a 10 million ton sulfur dioxide emissions reductions for coal

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* Projected employment is derived by dividing coal production (tons of coal) by coal-miner productivity (tons of coal produced per miner). Therefore, for a given level of coal production, an increase in coal-miner productivity will produce a decrease in miner employment.

TABLE S.2

EFFECTS OF ACID RAIN CONTROL MEASURES ON REGIONAL COAL PRODUCTION
(Percent Change in Annual Production, 1979-1990)

Region	No Change In Regulations	5 Million Ton Acid Rain Control Program	10 Million Ton Acid Rain Control Program	13 Million Ton Acid Rain Control Program
NORTHERN APPALACHIA (Maryland, Northern West Virginia, Ohio, and Pennsylvania)	+ 10%	+ 1%	- 9%	- 13%
CENTRAL APPALACHIA (East Kentucky, Southern West Virginia, Tennessee, and Virginia)	+ 49%	+ 62%	+ 70%	+ 74%
MIDWEST (Illinois, Indiana, and West Kentucky)	+ 33%	+ 12%	- 10%	- 17%
WEST	+138%	+145%	+158%	+165%

TABLE S.3

EMPLOYMENT IMPACTS IN 1990 FOR THE EASTERN U.S.
OF A 10 MILLION TON SULFUR DIOXIDE EMISSION REDUCTION
(figures in parentheses are negative numbers)

	Acid Rain Case Change From 1990 Base Case[1]		Acid Rain Case Change From 1979 Level		UMW Current Unemployment[2]
	Range[3]	%	Range	%	%
Alabama	(1000-1400)	(10)%[4]	(1100)-3000	(11)-29%	6%
Illinois	(3800-11,700)	(47)	(3300-7200)	(20-44)	10
Indiana	(1200-1800)	(20)	400-2600	9-58	23
Kentucky					
eastern	5900-8600	20	(400)-15,400	(1)-43	16
western	(1200-1800)	(15)	(1200-4300)	(11-38)	
Maryland	0	0	(100)-300	(12)-27	NA[5]
Ohio	(5700-8100)	(39)	(2400-6300)	(16-42)	46
Pennsylvania	(3100-4500)	(10)	(8100)-4400	(22)-12	18
Tennessee	(1200-1800)	(22)	800-2800	24-79	0
Virginia	2300-3300	18	(1000)-5800	(6)-36	5
West Virginia					
north	(1200-1700)	(7)	(1200-8200)	(5-34)	19
south	8100-11,600	14	33,600-62,700	105-196	

1. 1990 Base Case is what 1990 employment is projected to be in the absence of changes in environmental regulations.

2. For members of the UMW only. Figures are for April 1982.

3. The ranges represent various productivity assumptions, from a 10% decrease from 1979 levels to a 30% increase.

4. Percent change from base case is independent of productivity assumptions; therefore, no range is presented.

5. Not Available.

SOURCE: Office of Technology Assessment.

producing states east of the Mississippi. Employment effects are most severe in Illinois, Ohio, northern West Virginia, and western Kentucky — for these areas coal-mining employment is projected to decline more than 10 percent below current levels. Under a 10 million ton emissions reduction, employment in high-sulfur coal producing areas is projected to decrease by between 9,000 and 38,000 jobs over the time required to implement the reductions[*] (the range incorporates the uncertainty of future productivity).

These employment trends are accompanied by proportionate changes in direct miner income. At the national level, the monetary effects of coal market shifts are minimal because benefits to low-sulfur regions are projected to balance out costs to high-sulfur regions. This level of aggregation, however, obscures the regional distribution of coal-related economic costs. Direct income effects for a 10 million ton emissions reduction are listed below:

— Northern Appalachia: $300 to $400 million per year loss;
— Central Appalachia: $400 to $600 million per year gain;
— Midwest: $300 to $400 million per year loss;
— West: $200 to $300 million per year gain.

When indirect employment and income effects — which reflect the impact on other economic activities dependent on the coal mining sector — are included, total economic impacts may be 2 to 3 times greater. For the high-sulfur regions of Northern Appalachia and the Midwest, the economic costs of changes in the coal market would be added to costs of emissions reductions to electricity consumers that these same regions may incur.

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[*] To place these figures in perspective, there were 254,000 workers employed in the coal-mining industry nationwide in February 1982. There were 5.4 million people employed in all sectors in Illinois and 4.5 million in Ohio in April 1982.

S.3 ASSESSMENT OF POLICIES TO MITIGATE COAL MARKET IMPACTS

Policies are available to mitigate the effects of acid rain control measures on the coal market. Two approaches to mitigation are:

(1) The "technological approach", which involves requiring the use of control technologies by, for example, requiring that a percentage reduction of emissions be achieved regardless of the quantity of sulfur in the coal being burned; and

(2) The "local coal" approach, which involves regulating the coal consumption behavior of utilities on the basis of the location of the coal supply, as in Section 125 of the Clean Air Act.

These policies would increase utility industry costs of achieving emissions reductions, although the amount of this increase is uncertain. Besides imposing additional economic costs, these policies might also present political difficulties. In a Federal Register notice, EPA stated that Section 125 is "cumbersome, tending to create conflicts"; the agency casts "considerable doubt on the workability of this portion of the statute."

In addition to policies designed to avoid large shifts in coal markets, policies have been proposed to lessen the resultant hardship if the shifts were allowed to take place. Alternative policies might take the form of special adjustment assistance to workers, firms, and/or communities that are found to be significantly injured by the acid rain control measures.

Potential coal market shifts resulting from acid rain control measures could present difficult economic and distributional problems. Society can significantly reduce sulfur dioxide emissions and protect the high-sulfur coal industry, but only by constraining the market potential of the low-sulfur coal industry and by imposing additional costs to consumers of electricity. Whether these increased costs are warranted by the regional economic and employment benefits that may result is a significant issue confronting the Congress in the Clean Air Act reauthorization in 1982.

THE EFFECTS OF ACID RAIN CONTROL MEASURES ON THE COAL MARKET

I: OVERVIEW

Many legislative proposals for controlling acid rain have focused on reducing sulfur dioxide emissions in the eastern United States. By significantly increasing the value of low-sulfur coals as compared to high-sulfur coals, emissions reductions designed to control acid rain create the potential for significant shifts in the coal market. Because the sulfur content of coal varies significantly from region to region throughout the United States, any emission reduction strategy that relies even in part on "switching" to lower sulfur coals can potentially affect the regional distribution of coal production and employment. These changes in the coal market could be accompanied by social dislocations as some areas experience rapid economic growth and others, declines.

This analysis is organized in the following manner:

- Part II disusses the characteristics of U.S. coal reserves and production as a basis for the potential patterns of change in regional coal production as a result of potential acid rain control measures.
- Part III assesses the potential magnitude of changes in regional coal production resulting from acid rain control measures, and the economic consequences of these changes. OTA uses as the basis for its estimates results of a computer model that projects region-by-region changes in coal production due to sulfur dioxide emissions reductions of 5, 10, and 13 million tons. OTA has combined these production projections with coal-miner productivity and income data to project the effects of acid rain controls on regional coal employment and economic activity. These estimates will then be compared to similar analyses performed by Peabody Coal and the United Mine Workers of America.
- Part IV addresses the availability and efficacy of societal measures to mitigate potential social disruption caused by regional shifts in coal production due to acid rain controls.

II: FACTORS CONTRIBUTING TO POTENTIAL COAL MARKET SHIFTS

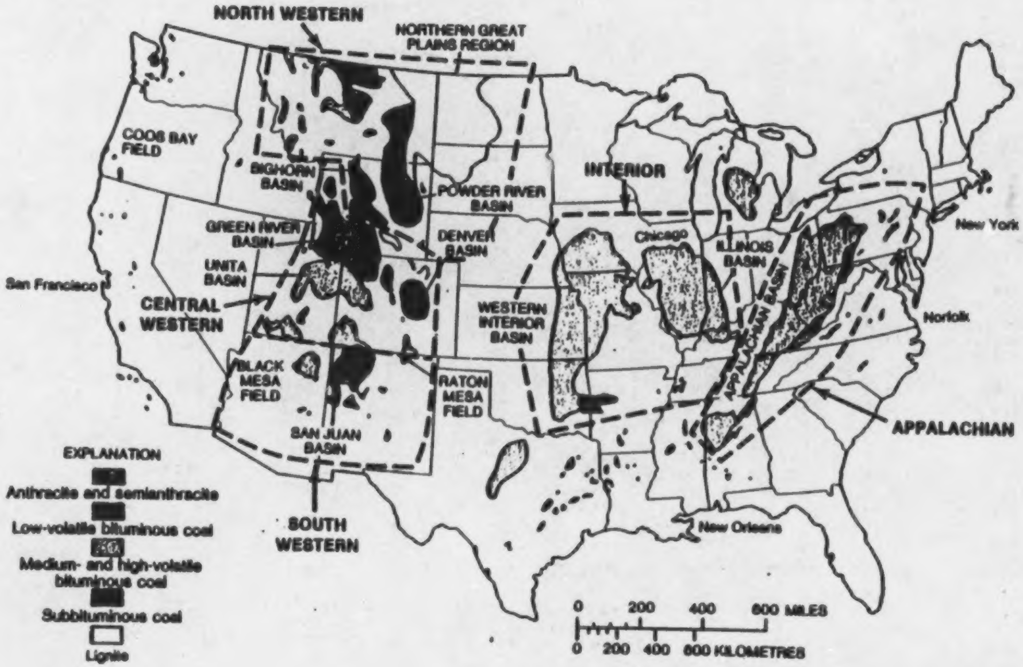
Regional coal production is largely determined by the consumption behavior of fuel users. Three factors influence the choice of coal supplies: (1) mine-mouth prices,(2) transportation costs, and (3) fuel quality (primarily the energy value and sulfur content).[1] Acid rain control measures would affect the economics of coal by significantly increasing the value of low-sulfur coal relative to high-sulfur coal, all other factors remaining equal.

Figure 1 shows the location of the nation's coal deposits. The regional character of the potential effects on the coal-market due to changes in sulfur dioxide emissions requirements stems from variations in the sulfur contents of coal among various geographical areas of the United States. Table 1 displays the distribution of each state's coal reserves by sulfur content category. A clear pattern emerges when one consults Figure 2. A large majority (74%) of coal reserves in the eastern United States are high in sulfur (greater than 2.0 pounds of sulfur dioxide per million Btu). By contrast, the majority (72%) of western reserves are low in sulfur (less than 1.2 lbs/MMBtu). The two significant eastern exceptions to this pattern are Kentucky and West Virginia. Both have significant quantities of reserves above and below 1.2 lbs/MMBtu.[2]

Table 2 analyzes each state's coal production for the utility market.[3] The first column presents the quantity of coal, in millions of tons, produced for the utility market by each state in 1980. The second column shows the percentage of that production that would not allow utilities to comply with a 1.2 pound per million Btu sulfur dioxide emission limit without applying control technologies. The third column presents the portion of this "non-compliance" coal that is sold on the spot market, i.e., is not covered by a

FIGURE 1

U.S. COAL FIELDS


NORTH WESTERN
NORTHERN GREAT PLAINS REGION
COOS BAY FIELD
BIGHORN BASIN
POWDER RIVER BASIN
INTERIOR
GREEN RIVER BASIN
DENVER BASIN
Chicago
ILLINOIS BASIN
New York
San Francisco
UNITA BASIN
CENTRAL WESTERN
WESTERN INTERIOR BASIN
APPALACHIAN BASIN
Norfolk
BLACK MESA FIELD
RATON MESA FIELD
APPALACHIAN
SAN JUAN BASIN
SOUTH WESTERN
New Orleans
EXPLANATION
Anthracite and semianthracite
Low-volatile bituminous coal
Medium- and high-volatile bituminous coal
Subbituminous coal
Lignite
0 200 400 600 MILES
0 200 400 600 KILOMETRES

SOURCE: P. Averitt, *Coal Resources of the United States, Jan. 1, 1974*, U.S. Geological Survey Bull, 1412, at 5 (1975).

Table 1

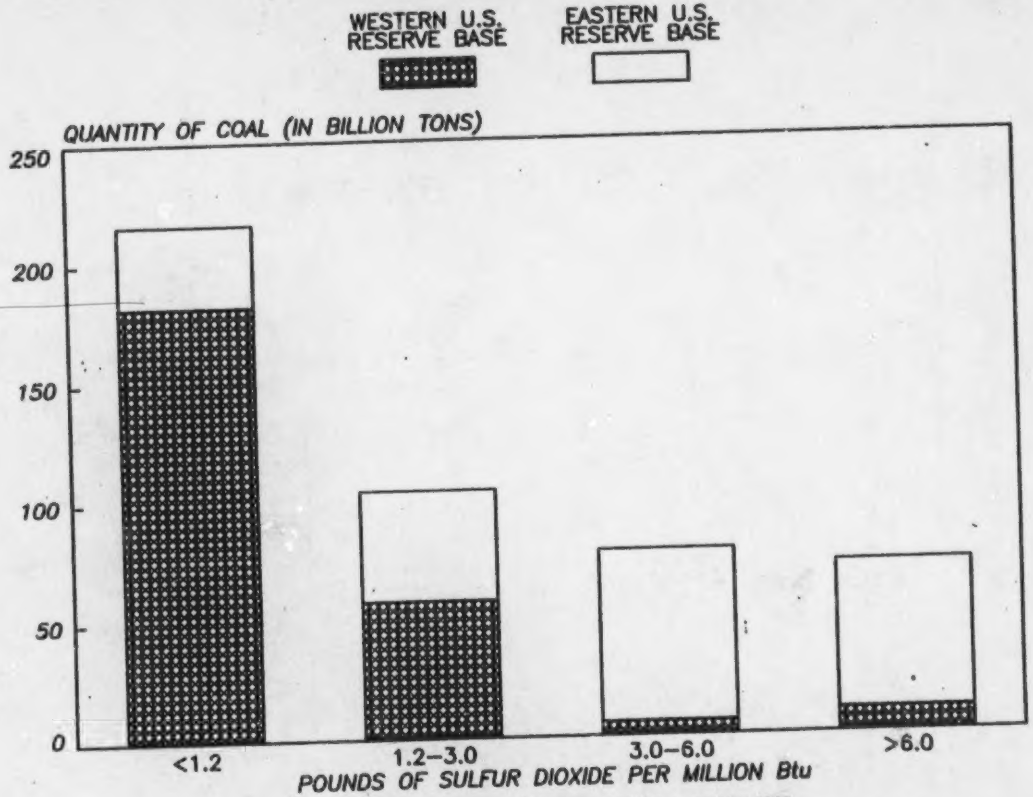
DEMONSTRATED RESERVE BASE BY SULFUR CATEGORY
QUANTITIES IN MILLIONS OF TONS
SULFUR CATEGORIES IN LBS SO2 PER MMBTU

STATE	<.5	.9-1.2	1.3-1.5	1.5-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.0	TOTAL
ALABAMA	5	1,775	1,712	1,074	1,756	438	0	0	0	6,760
GEORGIA	0	0	4	0	0	0	0	0	0	4
ILLINOIS	0	0	0	4,359	1,581	3,151	3,107	14,248	41,260	67,705
INDIANA	0	212	992	1,304	503	453	2,018	1,976	3,161	10,621
KENTUCKY	0	10,210	3,846	1,473	410	749	1,556	7,524	8,472	34,240
MARYLAND	0	1	5	296	65	175	178	107	0	826
MICHIGAN	0	0	0	0	95	0	26	0	7	128
NORTH CAROLINA	0	0	11	0	0	0	0	0	0	11
OHIO	0	0	0	0	1,119	1,294	6,684	4,429	5,509	19,035
PENNSYLVANIA	16	568	587	1,992	8,581	12,203	3,757	1,684	1,039	30,428
TENNESSEE	0	189	135	154	154	42	234	31	39	998
VIRGINIA	784	1,469	458	561	148	118	0	0	0	3,538
WEST VIRGINIA	3,407	13,724	2,932	2,791	6,029	3,084	3,535	355	4,128	39,985
EASTERN US TOTAL	4,212	28,149	10,681	14,005	20,440	21,726	21,096	30,353	63,616	214,277
ALASKA	5,805	18	332	0	0	0	0	0	0	6,155
ARIZONA	0	0	0	399	25	0	0	0	0	424
ARKANSAS	0	11	23	260	43	74	0	0	0	411
COLORADO	7,800	2,212	4,841	213	1,150	0	0	0	0	16,215
IDAHO	0	0	4	0	0	0	0	0	0	4
IOWA	0	0	0	0	0	0	0	71	2,127	2,199
KANSAS	0	0	0	0	0	190	123	210	472	995
MISSOURI	0	0	0	0	0	0	518	0	5,559	6,077
MONTANA	84,247	32,786	1,410	1	1,527	0	0	0	499	120,469
NEW MEXICO	1,277	508	2,701	7	48	0	0	0	0	4,541
NORTH DAKOTA	564	165	1,961	2,908	2,244	1,524	604	0	0	9,971
OKLAHOMA	8	750	280	26	332	144	0	21	83	1,644
OREGON	12	0	0	6	0	0	0	0	0	17
SOUTH DAKOTA	0	0	193	74	0	99	0	0	0	366
TEXAS	0	0	0	0	12,693	0	0	0	0	12,693
UTAH	399	4,733	158	0	178	1,033	0	0	0	6,502
WASHINGTON	843	16	0	578	0	143	0	0	0	1,580
WYOMING	33,527	8,560	1,007	24,214	2,606	4	0	0	95	70,014
WESTERN US TOTAL	134,482	49,761	12,911	28,685	20,845	3,212	1,246	302	8,835	260,279
UNITED STATES	138,694	77,909	23,592	42,690	41,285	24,938	22,341	30,655	72,451	474,556

Source: U.S. Department of Energy, Demonstrated Reserve Base of Coal in the United States on January 1, 1979, DOE/EIA-0280(79), May, 1981,

FIGURE 2

DEMONSTRATED RESERVE BASE BY SULFUR CATEGORY



OFFICE OF TECHNOLOGY ASSESSMENT, PECHAN & ASSOC., 1982

TABLE 2

COAL PRODUCTION FOR THE DOMESTIC UTILITY MARKET

	1980 Production for the Utility Market (millions of tons)	Percentage Non-Compliance*	Percentage Non-Compliance Sold on the Spot Market	Percentage Non-Compliance Exported to Other States
Alabama	15.8	82.5%	17.3%	10.1%
Arizona	10.5	0.0	0.0	0.0
Colorado	13.6	7.1	0.4	2.8
Illinois	53.4	99.9	6.6	66.0
Indiana	27.3	99.9	8.3	22.1
Iowa	0.4	95.9	14.5	0.0
Kansas	0.7	100.0	29.3	81.7
Kentucky	112.4	89.9	16.5	72.9
East	73.9	83.2	19.0	75.1
West	38.5	100.0	11.8	68.7
Maryland	1.2	100.0	22.8	24.7
Missouri	5.0	100.0	6.9	33.5
Montana	27.9	63.6	0.0	51.9
New Mexico	17.0	69.8	0.3	1.2
North Dakota	15.3	99.2	13.6	20.8
Ohio	34.3	100.0	18.9	26.5
Oklahoma	2.7	98.6	17.3	98.6
Pennsylvania	50.9	99.1	29.9	30.1
Tennessee	7.6	86.7	17.6	34.6
Texas	27.0	100.0	0.0	0.0
Utah	8.5	20.0	1.1	7.1
Virginia	13.8	87.5	10.6	71.0
West Virginia	53.1	81.3	8.1	39.4
North	30.8	97.8	7.5	46.1
South	22.3	58.5	8.8	30.1
Wyoming	89.7	16.6	0.9	9.9

* "Non-compliance" coal is defined as the amount of coal produced by a state that would not permit utilities to comply with a 1.2 pound of sulfur dioxide per million Btu emissions limit without applying control technologies.

SOURCE: From DOE/EIA Form 423 data, supplied to OTA by E.H. Pechan and Associates.

contract between a utility and a mining company. Non-compliance coal sold on the spot market is likely to be most vulnerable to more stringent sulfur dioxide regulations.[4] The final column shows the portion of non-compliance coal that is exported to other states — an indicator of the potential efficacy of state-level policies designed to minimize coal market disruptions (discussed further in the final section).

III: PROJECTIONS OF CHANGES IN REGIONAL COAL PRODUCTION, EMPLOYMENT, AND ECONOMIC ACTIVITY

A. METHODS USED IN THE ANALYSIS

1. Projections of Regional Coal Production

The projections for regulation-induced changes in regional coal production presented in this report are based on a computer model modified by ICF, Inc., from the DOE National Coal Model. ICF's Coal and Electric Utilities Model (CEUM) makes it possible to compare: (1) projections of regional coal production in 1990 (and 2000) assuming that current sulfur dioxide emissions standards are maintained, and (2) projections of regional coal production in 1990 (and 2000) if significant sulfur dioxide emissions reductions, designed to control acid rain, are required. The ICF model has been used to project the effects of acid rain control proposals by: The Environmental Protection Agency, the Department of Energy, the Edison Electric Institute, and the National Wildlife Federation and National Clean Air Coalition. The model results presented here were not performed by ICF for OTA, but for the other groups mentioned above.

CEUM is a "least-cost optimization model" that chooses the combination of scrubbers, coal washing, and low-sulfur coal substitution or blending that minimizes cost to the utility industry of achieving emissions reductions.[5] The changes in the choice of coals consumed alter regional patterns of coal production. These projected production shifts form the basis for OTA's estimates.

This report uses four ICF sulfur dioxide emissions reduction scenarios, and their attendant regional coal production scenarios, to analyze the potential magnitude of coal market impacts:

(1) Scenario I: a five million ton reduction of utility sulfur dioxide emissions by 1990, allocated according to a "regional (31-state) least cost" approach;

(2) Scenario II: a 10 million ton sulfur dioxide emissions reduction by 1990, allocated according to the formula in S.1706 (i.e., based on emissions in excess of an emissions rate of 1.2 pounds of sulfur dioxide per million Btu);

(3) Scenario III: a 13 million ton sulfur dioxide emissions reduction by 1990, allocated according to a formula similar to S.1706 and;

(4) Scenario IV: a 10 million ton reduction reduction, allocated according to a "regional least cost" approach, that shows regional coal production shifts out to the year 2000.[6]

These scenarios are used solely to illustrate the potential magnitude and direction of coal market shifts associated with the least-cost solution to the utility industry of various regulatory strategies for controlling acid rain. The model cannot predict how various acid rain proposals would, in practice, be implemented. Some analysts assert that the ICF model seriously underestimates the amount of fuel-switching that is likely to occur, while others suggest that its fuel-switching estimates are overstated.[7]

Several important factors that might influence the accuracy of ICF's projections are:

(1) Innovation in pollution control technology: The amount of fuel-switching projected to occur depends on the relative cost of that approach as compared to other emission reduction options. The ICF model attempts to reflect the best current estimates of the cost of various control options. If innovations were to significantly reduce the costs of control technology relative to fuel switching, smaller

changes in regional coal production would accompany any given level of emissions reductions.

(2) Utility regulatory policy: The structure of utility rate-making may affect which emissions reduction options are most attractive to utilities. For instance, fuel adjustment provisions that allow utilities to pass increased fuel costs through to consumers without the need for a rate hearing may make fuel switching seem more attractive to utility managers than the ICF model would suggest.[8]

(3) Transportation costs: The penetration of low-sulfur western coal into eastern and midwestern utility markets is very dependent on railroad rates. A rapid escalation in western rail rates could raise the delivered price of western coal, and hence reduce the magnitude of regional shifts.

(4) Electricity growth rates: While assumptions of rate of growth in electricity demand should not significantly affect the relative amount of fuel switching as opposed to other control options, the absolute magnitude of projected increases in coal production by 1990 is highly dependent on assumptions of electricity demands.

2. Forecasting Coal Mine Employment and Economic Changes

OTA combines production projections generated by the ICF model with coal-miner productivity and income data to project the effects of acid rain controls on regional employment and economic activity. Employment in the coal mining industry is determined by two factors: the level of coal production (tons of coal) and the rate of worker productivity (tons of coal produced per miner. Historically, changes in employment have been due more to changes in productivity than to changes in production.[9] Therefore, forecasting employment requires incorporating some provision for the uncertainty of future productivity levels. This analysis presents projected coal-mine employment changes as ranges reflecting different assumptions of future productivity levels: a lower bound of a 10% decline from 1979 productivity levels and an upper bound of a 30% increase.[10] These employment projections are combined with miner income data to estimate the "direct" income impacts of acid rain controls.

Estimates of direct income effects do not reflect the full extent of the impact of changes in coal-mine employment. Economic activities dependent upon the coal-mining industry, such as rail transport and the retailers who provide household goods for coal-mine industry employees, are also affected. These indirect economic effects are likely to be quite significant in comparison to the direct effects, but are extremely difficult to estimate. Indirect effects could be realized as reductions in employment, as reductions in income to the employed, or some combination of both. In this analysis, direct income effects are combined with an income "multiplier", which provides a very rough approximation of the amount of regional economic activity that is dependent on coal mining, to derive "total" income effects of acid rain controls.[11]

C. SUMMARY OF REGIONAL ANALYSIS: PROJECTED PATTERNS OF CHANGE

Table 3 summarizes the impacts of 5, 10, and 13 million ton sulfur dioxide emissions reductions on regional coal production, employment, and economic activity. Several generalizations emerge from the analysis. First, the model projects significant growth in coal production nationwide (about 60%) between 1979 and 1990. Second, regulations designed to control acid rain, even those calling for the largest emissions reductions, do not alter the projected increases in national production. Even with the additional costs of acid rain controls, the competitiveness of coal with other fuels is not projected to suffer.

Third, even though acid rain control measures are not projected to produce changes in nationwide production, the ICF model projects that a redistribution of coal production among regions is projected to take place. Regions with low-sulfur reserves are projected to experience production growth

TABLE 3 SUMMARY TABLE OF REGIONAL COAL MARKET EFFECTS OF ACID RAIN CONTROL LEGISLATION

REGION	5 MILLION TON SULFUR DIOXIDE EMISSION REDUCTION	10 MILLION TON SULFUR DIOXIDE EMISSION REDUCTION	13 MILLION TON SULFUR DIOXIDE EMISSION REDUCTION
NORTHERN APPALACHIA (Maryland, Northern West Virginia, Ohio and Pennsylvania)	Under current environmental regulations, annual coal production is projected to increase approximately 10 percent between 1979 and 1990; under a 5 million ton acid rain control program no change in production is projected over this period. Employment opportunities foregone are projected to range from 6,300 to 9,100 jobs (a 10 percent reduction); because there is no projected production change, employment changes from 1979 levels will be a function of productivity changes only. Direct income opportunities foregone by the regional economy are projected to be $160 to $230 million; total income opportunities lost could range from $450 to $640 million.	Under a 10 million ton acid rain control program, production is projected to decrease by about 10 percent between 1979 and 1990. Employment is projected to be 15 percent (9,800 to 14,100 jobs) less than it would have been under the 1990 base case; projected employment changes from 1979 levels range from no change to a 30 percent (23,000 job) decrease. Direct income opportunities foregone range from $250 to $360 million; total income foregone ranges from $630 to $910 million. Available projections for the year 2000 suggest these declines may only be temporary.	Under a 13 million ton acid rain control program, production is projected to decrease 13 percent between 1979 and 1990. 1990 employment levels are projected to be 20 percent (12,700 to 16,500 jobs) less than what they would have been in 1990 under current regulations, and 14 to 35 percent (10,800 to 26,100 jobs) below 1979 employment. Direct income opportunities foregone range from $330 to $470 million; total income foregone is projected to be $810 million to $1,170 million.
CENTRAL APPALACHIA (Eastern Kentucky, Southern West Virginia, Tennessee, and Virginia)	Under current environmental regulations, annual coal production is projected to increase by about 50 percent between 1979 and 1990; under a 5 million ton acid rain control program, a 62 percent increase is projected over this period. Employment is projected to be about 10 percent (8,800 to 12,700 jobs) greater than it would have been in 1990 under current regulations; projected employment changes from 1979 levels range from 25 to 80 percent (21,800 to 69,900 jobs) increase. Direct annual income opportunities created in this region range from $230 to $330 million; total annual income created ranges from $450 to $640 million.	Under a 10 million ton acid rain control program, production is projected to increase 70 percent between 1979 and 1990. 1990 employment levels are projected to be about 15 percent (15,000 to 21,700 jobs) greater than they would have been in 1990 under current regulations, and 38 to 99 percent (33,200 to 86,500 jobs) greater than 1979 employment levels. Direct income opportunities created are projected to be $390 to $560 million; total income generated ranges from $1,030 to $1,490 million.	Under a 13 million ton emission reduction, production is projected to increase 75 percent between 1979 and 1990. 1990 employment levels are projected to be 16 percent (17,300 to 25,000 jobs) greater than what they could have been in 1990 under current regulations, and 40 to 100 percent (35,800 to 90,000 jobs) above 1979 levels. Direct income opportunities created by the projected increase in coal production range from $440 to $640 million; total income generated ranges from $1,200 to $1,700 million.

TABLE 3 (continued)

REGION	5 MILLION TON SULFUR DIOXIDE EMISSION REDUCTION	10 MILLION TON SULFUR DIOXIDE EMISSION REDUCTION	13 MILLION TON SULFUR DIOXIDE EMISSION REDUCTION
MIDWEST (Illinois, Indiana, and Western Kentucky)	Under current environmental regulations, annual coal production is projected to increase 31 to 34 percent between 1979 and 1990; under a 5 million ton reduction, production is projected to increase 12 percent over this period. 1990 employment levels are projected to be 16 percent (5,400 to 7,300 jobs) less than what they would have been in 1990 under current regulations, and between a 13 percent (4,200 job) decrease and a 25 percent (8,000 job) increase from 1979 levels. Direct income opportunities foregone range from $140 to $200 million; total income foregone ranges from $370 to $530 million.	Under a 10 million ton acid rain control program, production is projected to decrease 10 percent between 1979 and 1990. 1990 employment levels are projected to be 33 percent (10,500 to 15,200 jobs) below what they would have been in 1990 under current regulations, and 6 to 35 percent (1,900 to 11,300 jobs) less than 1979 employment. Direct income opportunities foregone are projected to range from $270 to $390 million; total income foregone ranges from $770 million to $1,100 million. Projections for the year 2000 suggest these declines may be reversed in the period 1990 to 2000.	Under a 13 million ton sulfur dioxide emission reduction, production is projected to decrease by 17 percent between 1979 and 1990. Employment is projected to be 38 percent (12,100 to 17,400 jobs) below what it would have been in 1990 without an acid rain control program; projected employment decreases from 1979 levels range from 13 to 40 percent (4,200 to 12,900 jobs). Direct income opportunities foregone range from $310 to $480 million; total income foregone ranges from $870 million to $1,200 million.
THE WESTERN U.S.	Under current environmental regulations, annual coal production is projected to increase approximately 138 percent between 1979 and 1990; under a 5 million ton acid rain control program, production is projected to increase 145 percent over this period. 1990 employment levels are projected to be 3 percent (1,200 to 1,700 jobs) higher than what they would have been in 1990 under curent regulations, and 80 to 160 percent (16,600 to 32,900 jobs) above 1979 levels. Direct income opportunities created by acid rain controls are projected to range from $30 to $40 million; total income benefits are projected to be $120 to $170 million.	Under a 10 million ton acid rain control program, production is projected to increase 158 percent between 1979 and 1990. 1990 employment is projected to be 13 percent (4,600 to 6,700 jobs) greater than what it would have been in 1990 in the absence of acid rain controls, and between 95 and 180 percent (19,100 to 36,300 jobs) greater than 1979 levels. Increases in direct income opportunities range from $120 to $170 million; total income increases are projected to range from $510 to $740 million.	Under a 13 million ton sulfur dioxide emission reduction, production is projected to increase 165 percent between 1979 and 1990. Acid rain controls are projected to increase employment opportunities by 20 percent (6,800 to 9,800 jobs) over what they would have been in 1990 without any change in environmental regulations. 1990 employment levels are projected to be 105 to 196 percent (21,000 to 39,300 jobs) greater than 1979 levels. Direct income opportunities created in the region are projected to range from $180 to $250 million; total income benefits range from $750 million to $1,100 million.

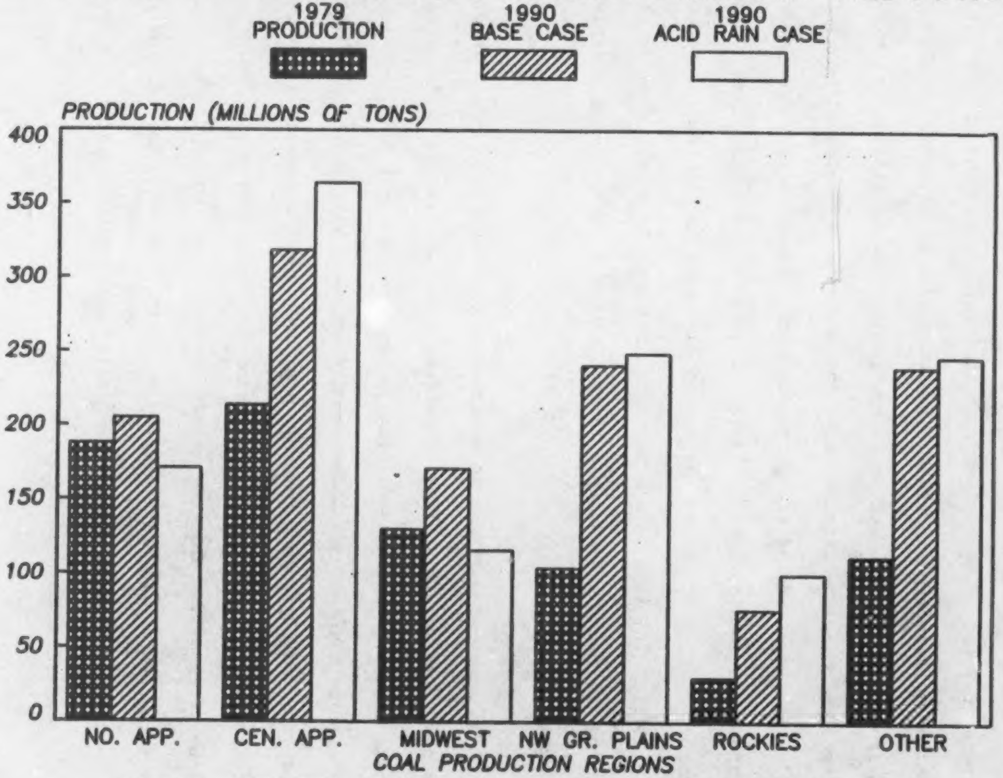
beyond what would occur absent any change in regulations. On the other hand, between 1979 and 1990, regions with high-sulfur reserves are projected to experience production declines below what 1990 levels would be if regulations had remained the same, and — in the case of the 10 million ton and greater reductions of sulfur dioxide emissions — below 1979 production levels as well. The magnitude of the projected redistributions increases as sulfur dioxide emissions reductions increase, although in a less than linear fashion.[12] Figure 3 shows the projected change in regional coal production from 1979 to (a) 1990 levels assuming no change in sulfur dioxide standards; and (b) 1990 levels assuming a 10 million ton sulfur dioxide emissions reduction.[13]

The areas most likely to experience significant growth in production are Southern West Virginia, Eastern Kentucky, and the regions west of the Mississippi (particularly Colorado). The regions most likely to experience significant declines are those of Northern West Virginia, Ohio, Western Kentucky, and Illinois. However, available model projections for the year 2000 suggest that these declines below current levels may be reversed in the decade after 1990. This projected rebound in production is due to general trends in the energy market, such as growth in utility demand, and the fact that an increasing number of new plants regulated under the 1979 New Source Performance Standards will come on line after 1990.

Employment patterns are projected to correspond to changes in production. However, the uncertainty regarding future productivity trends creates a larger band of uncertainty for employment effects than for production effects. The loss of portions of the market for high-sulfur coal could force the Midwestern and Northern Appalachian regions to forego

FIGURE 3

REGIONAL COAL PRODUCTION: EFFECTS OF A 10 MILLION TON SULFUR DIOXIDE EMISSION REDUCTION



SOURCE: OFFICE OF TECHNOLOGY ASSESSMENT, ADAPTED FROM ICF, INC.

employment opportunities on the order of 10 to 40% of what the coal-mining workforce is projected to be in 1990 in the absence of acid rain control legislation. The areas of northern West Virginia, Ohio, western Kentucky, and Illinois are projected to experience actual employment decreases below 1979 levels for emissions reductions of 10 million tons and greater. Table 4 displays projected coal-mine labor force impacts of a 10 million ton sulfur dioxide emissions reduction for coal-producing states east of the Mississippi.

These projected employment impacts would be accompanied by proportional changes in direct miner income and total monetary impacts. For each of the high-sulfur coal regions of Northern Appalachia and the Midwest, these costs range from $200 million to $500 million in direct annual income losses to miners, and from $400 million to $1,200 million in total (direct plus indirect) annual monetary losses. The coal-related benefits in Central Appalachia range from $200 to $600 million annually in direct income gains, and total annual income gains of $700 to $1,700 million. These figures, particularly in the case of total monetary impacts, must be considered very rough estimates.

Changes in coal-related employment and income may present some community-level social and economic impacts repercussions. In areas projected to experience significant declines in employment, decreases in tax revenues could cause the quantity or quality of community services to decline. In areas projected to experience rapid increases in employment, the capacity of communities to provide adequate health care, housing, education, and so on, may be strained.

Comparison with other Studies

Peabody Coal and the United Mine Workers have performed similar estimates

TABLE 4

EMPLOYMENT IMPACTS IN 1990 FOR THE EASTERN U.S. OF A 10 MILLION TON SULFUR DIOXIDE EMISSION REDUCTION

(figures in parentheses are negative numbers)

	Acid Rain Case Change From 1990 Base Case[1]		Acid Rain Case Change From 1979 Level		UMW Current Unemployment[2]
	Range[3]	%	Range	%	%
Alabama	(1000-1400)	(10)%[4]	(1100)-3000	(11)-29%	6%
Illinois	(3800-11,700)	(47)	(3300-7200)	(20-44)	10
Indiana	(1200-1800)	(20)	400-2600	9-58	23
Kentucky					
eastern	5900-8600	20	(400)-15,400	(1)-43	16
western	(1200-1800)	(15)	(1200-4300)	(11-38)	
Maryland	0	0	(100)-300	(12)-27	NA[5]
Ohio	(5700-8100)	(39)	(2400-6300)	(16-42)	46
Pennsylvania	(3100-4500)	(10)	(8100)-4400	(22)-12	18
Tennessee	(1200-1800)	(22)	800-2800	24-79	0
Virginia	2300-3300	18	(1000)-5800	(6)-36	5
West Virginia					
north	(1200-1700)	(7)	(1200-8200)	(5-34)	19
south	8100-11,600	14	33,600-62,700	105-196	

1. 1990 Base Case is what 1990 employment is projected to be in the absence of changes in environmental regulations.

2. For members of the UMW only. Figures are for April 1982.

3. The ranges represent various productivity assumptions, from a 10% decrease from 1979 levels to a 30% increase.

4. Percent change from base case is independent of productivity assumptions; therefore, no range is presented.

5. Not Available.

SOURCE: Office of Technology Assessment.

of employment and economic impacts resulting from proposed acid rain legislation. The most recent of these analyses was presented by UMW in April, 1982.[14] In that analysis, UMW stated that S.1706 (the Mitchell bill) would result in a loss of 89,000 jobs in the coal mining industry, resulting in direct economic losses of $2.4 billion and total (direct plus indirect) economic losses of $6.6 billion. These estimates measure the effects on high sulfur coal producing areas only.

Table 5 compares the UMW and OTA estimates. The UMW estimates assume that all reductions will be met by switching to lower-sulfur coal, and therefore should be considered an absolute upper bound for employment and economic losses from a 10 million ton sulfur dioxide emissions reduction. OTA assumes that the emissions reductions are met by a combination of fuel-switching and scrubber installation. In addition, whereas UMW considers "dislocations" of miners from their jobs, OTA averages job losses with job gains within states. OTA's estimates are between 57 and 90% lower than UMW's.[15]

Assessing the net effect of acid rain legislation on nation-wide coal production, employment, and economic activity, however, requires consideration of the offsetting increases in employment and economic activity in low-sulfur coal regions. When these are considered in aggregate, OTA estimates no significant change in employment and economic activity as a result of acid-rain induced production changes. OTA's estimates of the regional redistribution of coal-related acitivity, while by no means insignificant, are substantially less than the previous estimates performed by UMW and Peabody Coal.[16]

TABLE 5

Comparison of UMW/Peabody and Office of Technology Assessment Analyses of the Employment and Economic Impacts of S. 1706 in High-Sulfur Coal-Producing Areas

	UMW/Peabody[1]	OTA Change From 1990 Base Case[2]	OTA Change From Actual 1979 Levels
Employment Losses[3]	89,000	23,000-33,000	9,000-38,000
Direct Annual Economic Losses (Millions 1981 Dollars)[4]	$2,300	$600-$800	$200-$1,000
Total Annual Economic Losses (Millions 1981 Dollars)	$6,600	$1,600-$2,300	$600-$2,700

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1. UMW/Peabody assumes all of the 10 million ton emissions reductions will be achieved by switching to lower-sulfur coal.

2. OTA assumes, based on ICF analyses, that the requisite emissions reductions will be met by a combination of fuel-switching and scrubbers. The base case assumes no change in environmental regulations.

3. These employment losses occur over the period required to implement the pollution reductions. The ranges reflect uncertainty in future productivity levels. OTA bounds employment and economic estimates by assuming that productivity might rise as much as 30% or decrease by as much as 10% between 1979 and 1990.

4. Annual monetary estimates assume implementation of emissions reductions takes 10 years, as specified in the bill, and that shifts in coal production are distributed equally over that period.

PART IV: ASSESSMENT OF POLICIES TO MITIGATE COAL MARKET DISRUPTIONS

The preceding projections of acid rain regulation-induced changes in coal production, employment, and economic activity have all been based on a computer model designed to estimate the effects of achieving the emissions reductions at the lowest cost to the electric utility industry. The "least-cost approach" projects potentially significant impacts on the coal industry in some areas. Emissions reductions designed to reduce acid rain do not, however, necessarily entail these significant regional shifts in coal market activities.

Society can choose to pursue policies aimed at mitigating disruptions in the coal market. Two forms of policies are available to minimize the effects of acid rain control measures on the coal market:

(1) The "technological approach", which involves requiring the use of control technologies by, for example, requiring that a percentage reduction of emissions be achieved regardless of the quantity of sulfur in the coal being burned; and

(2) The "local coal approach", which involves regulating the coal consumption behavior of utilities on the basis of the location of the coal supply, as in Section 125 of the Clean Air Act.

The next section assesses policies designed to mitigate potential coal market disruptions accompanying large-scale sulfur dioxide emissions reductions. The information available to perform a comprehensive analysis of this subject is quite limited. Because of this constraint, the subject is approached in two ways. First, the one state for which some of the requisite information is available, Ohio, will be examined. Next, the potential consequences of invoking Section 125 of the Clean Air Act assuming alternative definitions of the statutory terms "significant" economic disruption and "locally or regionally" available coal supplies will be explored.

A. THE COSTS AND BENEFITS OF A TECHNOLOGICAL APPROACH TO MITIGATION

The technological approach to mitigation would require emitters to achieve their reductions by applying some circumscribed set of emissions control technologies, such as wet and dry flue-gas desulfurization units. To have some mitigative effect, the policy must minimize the potential cost advantage of switching to a lower-sulfur coal.

As presented earlier, Scenario II (S.1706) is projected to result in an employment decrease, for the state of Ohio, of between 5600 and 8100 workers from the base case. OTA estimates that if fuel-switching were prohibited in Ohio, the annual costs of sulfur dioxide emissions reductions would increase by as much as $136 million.[17] The benefits of this prohibition can be estimated by calculating the economic value of avoiding coal-industry employment losses.

To simplify the analysis, assume that a technology-based Federal regulation would totally eliminate fuel-switching from non-compliance coal. It follows that a technology-based state regulation imposed by Ohio would eliminate fuel-switching for, at most, that percentage of Ohio non-compliance coal consumed in Ohio, approximately 73% of Ohio's production for the utility market (as shown in Table 2).

If the state-imposed technology standard could mitigate 73% of the employment losses projected to occur from the base case, the direct economic benefits of saving these jobs would range from $105 to $155 million per year, an amount about equal to the additional control costs incurred. A federally-imposed, technology-based regulation would provide even greater benefits for

Ohio, but other states would then also incur increased control costs without gaining coal-related benefits.

B. ASSESSMENT OF SECTION 125 AS POLICY FOR THE MITIGATION OF COAL MARKET DISRUPTIONS

The second major approach available to policy-makers for mitigating the coal-market effects of proposed emissions reductions does not directly address emissions control techniques, but focuses instead on regulating the coal consumption of emitters based on the location of the coal supplier. Section 125 of the Clean Air Act allows states or EPA to prohibit the use of coals that are not produced "locally or regionally" if such an action would "prevent or minimize significant local or regional economic disruption or unemployment".[18] No ruling has yet been made under Section 125, although EPA has proposed a ruling based on a petition filed by the United Mine Workers and others in the state of Ohio in 1978.[19]

The potential significance of the Section 125 approach to mitigating coal market shifts is difficult to judge because neither the statute, nor EPA in its ongoing proceedings, have defined "significant" economic disruption or "locally or regionally" available coal.

1. The Consequences of Alternative Definitions of "Significant" Economic Disruption or Unemployment.

The case record provides little guidance as to how Section 125 might be applied if acid rain legislation were to be enacted.[20] However, it is possible to consider how extensively Section 125 might be invoked if acid rain control legislation were implemented. One can define alternative hypothetical "thresholds of significance", i.e., the level of impact judged by EPA to warrant the use of Section 125, and then analyze how many states these various definitions could apply to. Figure 4 shows states and regions of states to which Section 125 could be applied if the "threshold of significance" were alternatively defined as 10%, 20%, and 30% reductions in coal mine employment. The employment figures are based on emission reductions projected to occur under Scenario II — a 10 million ton sulfur dioxide emissions reduction, allocated according to the formula of S.1706.

As the figure shows, four areas would be threatened by coal employment losses of greater than 10% from 1979 levels: Ohio, Illinois, northern West Virginia, and western Kentucky.[21] Northern West Virginia is projected to experience a 15% (3600 job) decrease in coal-mining employment. Western Kentucky is projected to lose approximately 20% of its coal-mining employment, or about 2300 jobs. Ohio is projected to lose approximately 25% of its employment in coal mining, while for Illinois the percentage is slightly larger at 28%. These percentages represent approximately 3600 lost jobs in Ohio and 4500 in Illinois. There are no states for which coal-mining employment is projected to decrease by more than 30% below 1979 levels, under assumptions of constant productivity.

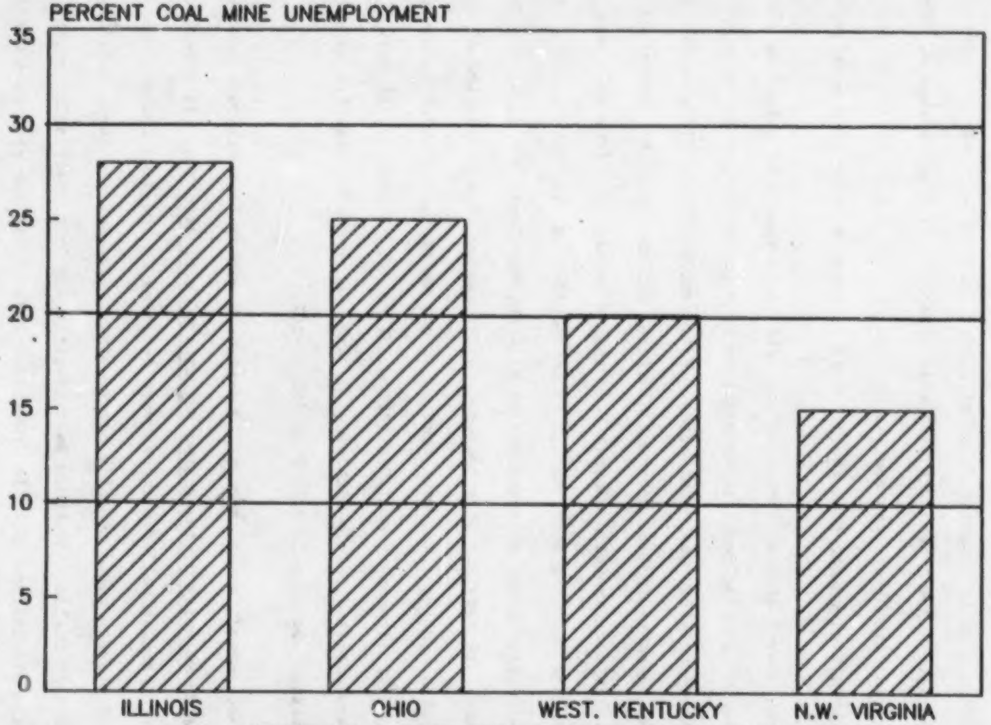
It is unclear whether the EPA Administrator would judge the impacts to be above the so-called "threshold of significance"; they do, however, meet the criterion of jeopardizing "the jobs of thousands of miners" cited in the rationale for the "reproposed" determination in the Ohio case.[22]

2. Consequences of Alternative Definitions of "Local or Regional" in Section 125

Two considerations influence the relationship between definitions of "local or regional" and the goal of maximizing coal market stability in the face of requirements for large-scale sulfur dioxide emissions reductions. The

FIGURE 4

STATES PROJECTED TO BE ELIGIBLE* FOR ACTION UNDER SECTION 125 GIVEN ALTERNATIVE "THRESHOLDS OF SIGNIFICANCE"



* ASSUMING A 10 MILLION TON SULFUR DIOXIDE REDUCTION AND THAT COAL MINE EMPLOYMENT IS THE CRITERIA FOR SIGNIFICANCE. SOURCE: OTA

first is the eventual destination of a state's coal production. If, for example, "local or regional" were to be defined as being synonymous with state boundaries,[23] invoking Section 125 would leave a state's high-sulfur coal production that is exported to other states vulnerable to regulation-induced disruption. Table 2 presents high-sulfur exports as a percentage of high-sulfur production for each coal state. As much as 66% of Illinois' and 82% of Kentucky's high-sulfur coal would remain vulnerable under such a definition.

The amount of coal protected can only be increased by expanding the area considered local or regional in order to incorporate larger percentages of states' high-sulfur coal production. For example, if the Illinois "region" were expanded to include Missouri, Indiana, and Michigan, the amount of noncompliance coal exported outside the "region" would fall from 66% (when considering only Illinois) to 21% (when considering all four states). For Pennsylvania, if the adjacent states of Ohio, Maryland, New York, New Jersey, Delaware, and Maryland were included in its region, the proportion of vulnerable coal — i.e., coal that would not be protected under potential Section 125 actions — would fall from 30% to 4%. Similarly, if Ohio's region were expanded to include Michigan, Indiana, and Pennsylvania, its amount of "vulnerable" coal would fall from 26% to 10%.

The second factor relevant to designing appropriate regional boundaries is the homogeneity of the characteristics of coal reserves. If reserves of vastly different sulfur contents were included in the same region, disruption of coal markets would probably not be minimized. For instance, defining a region that included Southern West Virginia and Ohio would still permit dramatic shifts from high- to low-sulfur coal within the statutory contraints of Section 125. The quantity of "compliance" reserves in southern West

Virginia is equivalent to 90% of the entire Ohio reserve base. On the other hand, Ohio and Northern West Virginia coals are sufficiently similar in sulfur content that one area's coal would probably not be significantly more attractive to regional buyers than another's.

Thus, Section 125 could effectively mitigate coal-market shifts resulting from proposed emissions controls only if regions were designed to include a significant portion of a state's coal customers, while excluding large reserves of coal with differing sulfur contents. In practice, a balance would have to be struck between defining regions large enough to protect sufficient amounts of coal, and small enough to exclude coal reserves of significantly different qualities.

The principal goal of the Clean Air Act is environmental protection. Section 125 is somewhat unusual in that its primary purpose is to mitigate economic impacts. It protects one economic sector (the high-sulfur coal industry) from actions taken by another sector (the utility industry) to comply with environmental standards.[24] As the analyses in sections 1 and 2 above suggest, definitional issues may present significant problems in implementing Section 125. Any decisions restricting competition among coal suppliers or defining what levels of unemployment warrant federal action are liable to evoke a great deal of political controversy. Indeed, EPA concludes that its "experience with Section 125 casts considerable doubt on the workability of this portion of the statute". EPA states that the process has proved to be cumbersome and conflict-creating.[25]

3. Other Mitigation Proposals

EPA's proposed determination under Section 125 states that "there should be a choice besides simply allowing the disruption to occur or interfering with the workings of a particular market to reduce an economic and employment impact". EPA presents a third alternative, analagous to programs providing adjustment assistance to workers, firms, and communities that have been injured by foreign competition because of free trade laws.[26] A policy could be designed to allow special compensation to workers and communities if they are seriously affected by environmental regulations. Workers could be given special retraining to help them find jobs in other industries in their communities. Or, if alternative employment opportunities are relatively unavailable in the areas in which workers now reside, payments could be provided to facilitate their movement to other areas where opportunities may be available.

4. Conclusions: Distributional Effects and Trade-offs

The net national effect of acid rain control measures on the coal production, employment, and economic activity is projected to be minimal: the economic opportunities created in low-sulfur coal producing areas tend to balance out the economic opportunities eliminated in high-sulfur areas. The coal-related impacts are thus almost entirely distributional in character. Policies are available, as discussed in Part IV, to moderate the coal market shifts threatened by acid rain control legislation. These policies, however, may be difficult to implement and would increase the costs of achieving the emissions reductions entailed by the control programs. Such costs would primarily take the form of further increases in the price of electricity (and the goods dependent thereon) as one departs from strategies designed to minimize emissions reduction costs to the utility industry.

The "coal issue" does not necessarily require policy choices between the vitality of the high-sulfur coal industry and reducing sulfur dioxide emissions. It is possible to have both. Society can significantly reduce sulfur dioxide emissions and protect the high-sulfur coal industry, but only by imposing costs on electricity consumers and constraining the market potential of the low-sulfur coal industry. Whether these additional costs are warranted by the regional economic and employment benefits that may result is a significant issue confronting the Congress in the Clean Air Act reauthorization of 1982.

FOOTNOTES FOR THE COAL ANALYSIS

1. For a discussion of the factors affecting the choice of coal, see Congressional Budget Office, The Utility Industry, the Coal Market, and The Clean Air Act, April, 1982; and Martin Zimmerman, The U.S. Coal Industry: The Economics of Public Choice, (Cambridge, MA: M.I.T. Press, 1981).

2. Kentucky and West Virginia account for 85% of the low-sulfur coal reserves east of the Mississippi. To place these figures in perspective, the low-sulfur coal reserves east of the Mississippi could sustain the entire level of United States coal production for a period of approximately 4 years (assuming 1979 coal produciton of 778 million tons, a growth rate of 3% per year, and 50% recoverability of reserves).

3. This data is derived from DOE Form 423, and has been supplied to OTA by E.H. Pechan and Associates.

4. The degree to which contracts constrain fuel-switching is a major uncertainty in this analysis. 88.5% of coal purchased in 1980 was purchased on contract. See D.O.E., Cost and Quality of Fuels for Electric Utility Plants: 1980 Annual, DOE/EIA-0191(80), p. 10.

   It is not clear whether changes in environmental regulations would absolve purchasers of their contractual obligations. A contract can contain provisions (such as "force majeure" clauses) which directly address the obligations of parties in the event of changes in environmental regulations. Buyer or seller could be relieved of all or part of the contractual obligations. See Scott, "Coal Supply Agreements", 23 Rocky Mountain Law Institute 107 (1979). In the absence of contractual language specifically dealing with these circumstances, a court could still allow a utility to avoid contractual responsibilities. It could interpret the language of the contract, or it could use common law doctrines and frame equitable relief which relieves the buyer of liability. Examples of common law principles available to the court are: mistake, impracticability, and frustration of purpose. See Calamari and Perillo, Contracts Ch. 13 (1977).

   Consolidation Coal Company has stated that it has one contract with the Lansing Board of Water and Light for 500,000 tons per year, broken because of state implementation plan requirements. An occurence more frequent than contract cancellation is simply the refusal to renew contracts when they expire. Personal communication with Daniel E. Rogers, of Consolidation Coal, April 14, 1982.

5. For a description of ICF's Coal and Electric Utilities Model see the executive summary in ICF, Inc., Capabilities and Experience in the Coal and Electric Utility Industries, May 1981.

6. For further description of these scenarios, see Appendix A of the OTA staff paper The Coal Question: The Impacts of Large-Scale Sulfur Dioxide Emissions on Regional Coal Production, Employment, and Economic Activity, forthcoming, June 1982. Scenario I was performed by ICF for ANL, DOE, and EPA. See Alternative Strategies for Reducing Utility SO_2 and NO_x Emissions, Draft Report, September 1981. Scenarios II and III were

performed by ICF for the Edison Electric Institute. See the EEI memo dated February 8, 1982 on ICF analysis of the Mitchell Bill (S.1706). Scenario IV was performed by ICF for the National Wildlife Federation and National Clean Air Coalition. See Cost and Coal Production Effects of Reducing Electric Utility Sulfur Dioxide Emissions, November 14, 1981.

7. For analyses asserting that ICF underestimates fuel switching, see the testimony of Chris Farrand of Peabody Coal Company on S.1706 to the Committee on Environment and Public Works, U.S. Senate, October 29, 1981. If this is the case, the projections presented here have underestimated the magnitude of regional redistribution of production.

   On the other hand, utility analyses of how the Mitchell bill would be implemented for their systems show little evidence of potential coal market disruptions. An analysis by American Electric Power (the nation's largest utility and coal consumer), states that only 4 of their 27 units would switch to lower sulfur fuels, while the others would retrofit scrubbers or be retired. See AEP, "Economic Impact Summary of Mitchell Bill (S.1706) on Customers of the AEP System", February 23, 1982. It should be noted that the ICF model assumes that no policies for minimizing the disruptions in the coal market are implemented (see Part IV).

8. Most public utility commissions do not allow utilities to earn a return on capital investment (such as a scrubber) until it becomes operational. Thus, because changes in fuel prices can be passed on immediately to consumers, utilities might prefer fuel switching. This could be counteracted somewhat by provisions allowing utilities to earn cash returns on "construction work in progress" before the equipment becomes operational.

9. Over the period 1960 to 1970, coal-mine employment declined from 190,000 to 144,000, a 3% average annual decrease. Over the same period, coal production increased from 434 million to 613 million tons, an average annual increase of 4%. The discrepancy between employment and production trends is accounted for by increases in average coal-miner productivity during this period. The average coal production per miner increased from about 12 to about 18.5 tons per day — an average annual increase of nearly 5%. The increasing proportion of surface mining — from 32% of annual production (or 139 million tons) in 1960, to 44% (or 270 million tons) in 1970 — accounts for some of the gains, since the average surface miner produces about 3 times as much coal per day as the average underground miner. In addition, surface miner productivity increased at an annual rate of 5.1% during this period, while underground miner productivity increased at a 2.7% annual rate. This productivity increase made it possible for production to increase with decreased employment. Data are from D.O.E., 1980 Annual Report to Congress: Volume 2, DOE/EIA-0173(80)/2; and The President's Commission on Coal, Coal Data Book, Washington, D.C., February 1980.

10. These productivity ranges have been chosen somewhat arbitrarily. The 30% increase in productivity was chosen as one bound because it reflects the historical maximum. The 10% decrease was chosen to account for factors that may contribute to decreased productivity, such as more stringent mine health and safety or surface reclamation regulations, or a shift from surface to underground mining. After a steady decline over the past 12

years, productivity is finally beginning to rise again, but future trends are uncertain. For a discussion of factors affecting worker productivity in coal mining see Office of Technology Assessment, Direct Use of Coal, April 1979, Chapter IV. See also Electric Power Research Institute, The Labor Outlook for the Bituminous Coal Mining Industry, EPRI EA-1477, Final Report, August 1980.

11. To arrive at employment estimates, OTA divides projected production increases by state-by-state productivity data developed from DOE data. These employment changes are then combined with miner salary data to arrive at direct income effects. Miner income was assumed to be $25,700 per year. This figure was taken from United Mine Workers of America, "Economic and Employment Impacts of Proposed Acid Rain Legislation", April 22, 1982. Indirect economic impacts were estimated using an "economic base technique". For each state, multipliers were developed by calculating the ratio of income derived from the "base" or "primary" sector to income derived from the "service" or "secondary sector". For furthur detail on the methodology used, see Appendix B of the OTA staff paper, supra footnote 6.

12. As emissions reduction requirements increase beyond a certain level, the proportion of reductions that are projected to be met by "fuel-switching" decreases relative to the proportion met by scrubbers.

13. Of the 90 million tons of annual production lost by the Eastern and midwestern high-sulfur coal market by 1990, about 50 million tons is gained by eastern low-sulfur producers and 40 million tons by western producers.

14. United Mine Workers of America, "Economic and Employment Impacts of Proposed Acid Rain Legislation", April 22, 1982.

15. Most of the difference can be attributed to different production change projections. On a national basis, UMW's projections of production losses to high-sulfur coal areas are approximately twice those of OTA. This difference overwhelms differences in productivity and multiplier data.

16. The Department of Energy has also performed some rough calculations on the coal-market effects of sulfur dioxide emissions reductions. DOE estimates that between 5100 and 6400 mine workers will be affected for every million tons of sulfur dioxide emissions reduction achieved through fuel-switching. Using the UMW assumption that all reductions are achieved through fuel-switching, DOE estimates between 51,000 and 64,000 jobs lost due to a 10 million ton emission reduction. See Department of Energy, Costs to Reduce Sulfur Dioxide Emissions, DOE/PE-0042, March 1982, p. 13 of appendix.

17. E.H. Pechan and Associates, Inc., Reducing Sulfur Dioxide Emissions for the Electric Utility Industry, prepared for the Office of Technology Assesment, p. 144. This is an OTA contractor report which will be available June, 1982.

18. Clean Air Act Section 125, 42 USC § 4725 (a) as modified by the National Energy Policy and Conservation Act of 1978, P.L. No. 96-619, Section 107,

92 STAT. 3286, 42 USC § 3286. Section 125 was modified by NEPCA to require that no ruling under Section 125 could "subject the consumer to significantly higher energy costs", a provision that further complicates the implementation of the Section.

19. 43 Fed. Reg. 60,654-55 (1978); 44 Fed. Reg. 52,031-32 (1979); 48 Fed. Reg. 8106-8109 (1981).

20. EPA has examined one case in which it was petitioned to invoke Section 125 by the United Mine Workers in Ohio. On December 28, 1978, EPA proposed to invoke Section 125 to prohibit several Ohio utilities from switching to coal that was not "locally or regionally available", based on the finding that utility actions to achieve SIP compliance in Ohio would decrease employment in the Ohio coal-mining industry by 35%. 43 Fed. Reg. 60,654-55 (1978). After public hearings and further investigation, EPA revised its estimate of employment losses to 6%. Based on these revised estimates, EPA proposed, on September 6, 1979, that these employment impacts "are not sufficiently significant to necessitate further action" under Section 125. 44 Fed. Reg. 52,031-2 (1979). Later, on January 26, 1981, EPA again revised its estimates. this time upward, to a 12.4% reduction in the mining labor forc [illegible] maintained that these impacts were below the "threshold of signficance" required to trigger the use of Section 125. 48 Fed. Reg. 8106-9 (1981). EPA has yet to make a final ruling on this case. For further detail on this case, see the OTA staff paper, supra footnote 6.

21. This assumes constant productivity. While unemployment in more states would be greater if productivity increased, those impacts are not the result of changes in the Clean Air Act — a condition required to trigger the use of Section 125.

22. 44 Fed. Reg. 52,031-32 (1979).

23. While it has presented no generalizeable ruling on the matter, in the Ohio case EPA does limit the area of consideration to the state. In its second reproposed determination of January 1981, EPA states:

> Ohio coal curtailments resulting from switches by out-of-state utilities, however, are not factored into the economic and employment impact estimates. EPA considers these curtailments to be outside the scope of the analysis for the Ohio Section 125 proceedings since the southeastern Ohio coal producing areas is not locally or regionally situated with respect to these out-of-state major fuel-burning stationary sources. 46 Fed. Reg. 8108.

EPA cites no rationale for excluding out-of-state utilities beyond this statement. It should be noted that the Ohio coal fields lie adjacent to Pennsylvania, West Virginia, and Kentucky, and thus in some cases defining local or regional as the state may exclude some major fuel-burning sources that are closer in proximity to the coal mine than some major fuel-burning sources in the state of Ohio.

24. For an analysis of the non-environmental consequences of the Clean Air Act Amendments of 1977, see Peter Navarro, "The Politics of Air Pollution",

The Public Interest, Spring 1980. See also Bruce Ackerman and William Hassler, *Clean Coal/Dirty Air*, (New Haven, CN: Yale University Press, 1981).

25. 46 Fed. Reg. 8109.

26. See the Trade Act of 1974. 19 USC Sections 2272-2293. The rationale for this provision is described in the following extract from the legislative history (P.L. 93-618):

> In the Trade Expansion Act of 1962, Congress established a special program of worker adjustment assistance in the belief that the special nature of employment dislocation resulting from changes in trade policy necessitated a level of worker protection somewhat beyond what is available through regular State unemployment insurance programs. Increases in imports of a given type of product can simultaneously and abruptly produce a combination of situations which have a particulary severe effect on employment. Because entire industries and not only individual firms may be adversely affected, workers may not have any realistic opportunity to find new empolyment which is at all related to the skills and training they may have accumulated over many years. Moreover, it can happen that the affected industry is one which is concentrated in a particular region with the result that the possibility of quickly absorbing displaced workers into others types of emplyment available in the area would be minimal. Thus, because trade-related unemployment may differ somewhat in nature from unemployment arising from other causes and because such trade-caused unemployment is a result of a Federal policy of encouraging increased foreign trade, worker adjustment assistance was provided for in the 1962 legislation.

For information on trade adjustment assistance programs, see Congressional Research Service, *Trade Adjustment Assistance for Workers: Program Growth and Changes*, Issue Brief Number IB80082, originated 8/22/80, update 12/8/81. For more general information on special jobless benefit programs, see National Commission on Unemployment Compensation, *Unemployment Compensation, Final Report*, July 1980, chapter 9.

APPENDIX

A Briefing on the Costs of Controlling Acid Rain

JUNE 2 AND 3, 1982

The briefing was moderated by Curtis Moore, associate counsel, Committee on Environment and Public Works.

Mr. **Moore**. We would like to reserve the front table for our staffs and obviously it is not going to be big enough. So the rest of our staffs will be scattered about the room.

We would like only one representative from each of the organizations at the table and if you have brought more than one person with you, try to have that person sit back from the table, we need the room. I will find out if we have everybody at the table by calling names. EPA is here, so is EEI. Wildlife Federation, Clean Air Coalition, Office of Technology Assessment, Peabody Coal, United Mine Workers, and DOE.

The order in which I just called your names is the order in which we would like you to make your presentations. Presentations should be limited to 10 minutes. Each of you should have a summary of your findings and a copy of the longer report which you have done.

As you start to make your presentation, please take it upon yourself to distribute around the table and to our committee staff and personal staff, copies of your summary and your presentation.

After all the presentations have been made, we will go to questions and answers and, of course, the priority on questions will come from the committee staff and the personal staff of our committee members.

I suspect that as we get into the question and answer period, it will be necessary to establish some ground rules on identification for purposes of the reporter.

I will read again and then pass out, until they are all gone, this list of the presentation order.

First, EPA; second, Edison Electric Institute; third, National Wildlife Federation/National Clean Air Coalition; fourth, Office of Technology Assessment; fifth, Peabody Coal; sixth, United Mine Workers; and, seventh, the Department of Energy.

Before we start, each of the institutions making a presentation today should have received, and our members should also have a two-page agenda which is really not so much an agenda as a description of what product we would like to have result from this briefing and the questions that ultimately we would like to have answered.

We are having additional copies of this agenda run off now and we will distribute them when they are brought in. But I assume each of the institutions presenting today does have this. Is that correct? Anybody who doesn't have it? Silence is assent.

Without further ado, we will listen to the Environmental Protection Agency.

Identify yourselves as you begin your presentations.

Mr. WAGNER. I was wondering, would it be possible to rearrange the presentation slightly to have DOE follow us?

Mr. MOORE: DOE asked to be last because they said they were going to be late. If you don't want to be last, it was for your convenience that we made that arrangement; that is fine.

PRESENTATION OF ENVIRONMENTAL PROTECTION AGENCY

Mr. WAGNER. Thank you for allowing us to come and present some results to you of the analysis that we have ongoing.

I am Marty Wagner. I am Acting Director of EPA's Energy Policy Division, more normally I am Chief of our Energy Economics Branch in our Office of Policy and Resource Management.

On my right is Paul Stolpman, who is Director of Policy Analysis in our Air Office and on my left is Jeannie Austin of my staff, who participated very much in this analysis.

We are giving you today tables of some analysis we have ongoing with the contractor that you probably have seen before called ITF.

We will present a report wrapped around these tables in about 3 weeks. It will take us a while to review the material we have got, put it together in a complete picture. Nonetheless, we thought it would be worthwhile to at least give you a sense of what our aggregate results are and some flavor of things to come in the report.

What we did is we evaluated a composite bill that embodied the elements of most of those being debated so far. We felt it would, given the amount of interpretations of what each bill means, be probably better to figure out a bill that was approximately like all of them, and analyze that fairly carefuly and then we would have a better understanding of the implications of certain changes.

This was done using ICF, the contractor, and it is an analysis pretty much along the ways you have seen before, somewhat different assumptions, but results will be similar to what DOE will be presenting. It is in the range. But we have been looking at a more focused view to understand the phenomenon involved of designing the bill of the sort being discussed.

Before jumping into the analysis, I would like to lay out some caveats. First, this is the result of a cost optimization model. It is an equilibrium analysis that really is not going to pick up effects changes in coal markets might have. You are going to have transients before things settle down to a new equilibrium. So I would suspect that our results might understate certain costs and certainly the rate of change that we see. We also have not looked at administrative costs, transactions costs. We made some assumptions about trading, that may or may not be trading of emissions reductions, that may or may not be true in the real world. And there is certainly going to be a lot of uncertainty around our results. We would rather present you a range of results than a point estimate, but unfortunately that was not possible to do.

Let me now move to the analysis.

The bill that we have examined is a 10 million ton reduction in the 31-State Eastern State Region that has been looked at before. Basically, all the States east of the Mississippi plus the tier of States on the west bank of the Mississippi. It is a 10-million ton reduction in SO_2 from existing sources, from existing power plants, looks at utility industry only. It caps all increases from existing sources, caps increases on both SO_2 and NO_x. It does not cap growth from new sources at all. The reductions are all indicated on an excess emissions basis where essentially all States or all sources emitting above 1.2 pounds per million Btu's. That goes into a pool of excess emissions and it is allocated based on that State's share of the regional pool of emissions.

We have allowed trading between NO_x and SO_2 with no NO_x equal to one SO_2 and the only trading we allow between sources is within States.

We do have an analysis which we would like to examine the results of looking at State-to-State trades, but we felt that we best stick to something we understood to present here. That will be in the report to follow.

Basically, in picking this approach, we were looking at trying to get the idea of the parameters of the bill where you have got essentially the reduction, how you are handling growth, how you define your baseline, what formula you allocate emissions on, how you are going to handle NO_x, the trading area, and also an issue which we have not yet looked at, which would be called default.

Some of the States have the option of defaulting; for example, 1.2 pound standard for all sources. We think the default could have a big effect on our results. We are not sure. One of the issues would be how you define a default, on a unit, system, State basis. Depending on how that works, you might see fairly significant results.

If you could turn to the table, Composite Bill Forecasts, second page, I have laid out here SO_2 emissions, NO_x emissions, annualized costs, cumulative capital costs, the costs per ton removed figure, percent changes in electricity rates, and also scrubber capacity. For comparison purposes, we will give you figures in 1980. We give you 1990 base case. We call that business as usual, and then we take changes from 1990 base and also changes from 1980.

In looking just at the Eastern States in 1980, there were 162 million tons of SO_2 emitted per year and the business as usual case, we would see that rising to 17.94; the bill we have examined, you find a reduction of 1/.54 in SO_2.

Let me do NO_x. Then we will return.

NO_x emission is 5.16 rising to 6.15, which would be reduced by 1.37 in this case. Probably the first question is, why are these numbers not adding to 10 million tons? Quickly, when you cap NO_x emissions, you are going to cap the growth in NO_x emissions and that will be nontrivial over the next 10 years; then the NO_x emissions reduce below today's levels at a two for one trading ratio, give you something toward SO_2, but SO_2 is growing anyway.

So a 10 million ton reduction works out to be more like 11 million ton reduction. Annualized costs in 1990 of this bill, \$3.7 billion, thereabouts; cumulative capital of $13 million; on a base of business as usual, spending about $164 billion, in this range. These costs are all in mid-year 1982 dollars.

Cost per ton removed on average, $330 a ton. That is for the SO_2 only.

NO_x costs are significantly cheaper per ton removed. We find that in some States marginal costs can be very much higher than these average costs. Certain States find themselves forced by this budget constraint to switch from, for example, low sulfur resid to distillate oil. We would like to examine these marginal costs a little more closely in certain States because some of these may be less estimates of real effects but sort of where you would see pressure and other things would be done that are not currently picked up in the analysis.

Percent changes on the electricity rates, an average of 3.6 percent, but in some States as high as 12.6, and about a doubling in scrubber capacity going from 23.9 to 37.1 gigawatts.

Jumping to the next page for coal production, we see a rather substantial coal shift in different parts of the country. Since I think I may be running out of time, we won't take you through the table in detail. You may notice that some of these coal shifts are substantial changes from even 1980 levels. Northern Appalachia in the Midwest suffers substantially as a result of the 10 million ton rollback.

Let me give you some specific State figures on what we would see happening. In a couple of States we can see fairly high impacts. We would see in this bill for Ohio a reduction of 40 percent from today's levels; in northern West Virginia, a reduction in 20 percent in coal production from today's levels; going to Illinois, the biggest reduction a 49 percent reduction Illinois coal production as a result of this bill.

Let me caution you on using State estimates. The veriability in or the uncertainty around our estimates for the States is certainly much larger than the uncertainty around the regions which is itself larger as an uncertainty for the Nation as a whole. However, they do indicate areas for concern and we would be planning on examining that in more detail, not necessarily in depth in the next 2 to 3 weeks, when we will be putting together our report, but suffice it to say that we see fairly substantial coal shifts as a result of this bill.

On the next page, I have just listed out critical assumptions. So you get some sense of how we went about doing this. I think only a couple of ones to key in on, the world oil price is probably lower than has been used in recent analyses based on the softening of the market that we have seen in recent years.

Electricity growth rate is lower than was used in some of the earlier analyses. And nuclear capacity estimates have dropped. I don't think these assumptions are going to change drastically the conclusions.

The last page is just a map, so you get a sense of what we mean when we say northern Appalachia, for example.

Those are the results. If I could just underscore that the results don't necessarily say something about true impacts in 1990, but they do tell you that according to how you design the bills of the sorts being discussed, you can have drastically different effects and where those effects occur can change quite a bit.

Primarily, what we have done here is take the first step in using a tool that helps us to understand essentially the forces that we are unleashing when we talk about the reductions of this magnitude.

Should I be answering questions now?

Mr. **Moore**. As I understand it, even though our order shows DOE as 7th, you would like to follow EPA?

Why don't you identify yourself and go ahead.

Mr. **Bartis**. We have some reports to hand out.

Mr. **Moore**. Before you go on, let me clarify one thing. EPA, as I understand it, did a three-volume report some time ago which some members of our staff have and most members of our staff do not have. Would it be possible for us to obtain 30 copies of that report for distribution to the committee staff and personal staff of members?

Mr. **Wagner**. EPA? Sure. It may take us a while to make copies. But you are speaking of the initial acid analysis or loading reduction analysis done about a year ago?

Mr. **Moore**. I presume. I have only seen a copy, a printed buff color.

Mr. **Stolpman**. Would you make sure you want all? Some of the regional ones are massive documents which are loaded with numbers and you may not want it.

Mr. **Moore**. Get us at least one so we can decide what we do want.

Mr. **Wagner**. How about if I give you 30 executive summaries and 1 or 2 complete sets.

Mr. **Freeman**. For the purposes of our presentation, we have had ICF compare the studies done for National Wildlife and National Edison Institute. That is included in the paper.

PRESENTATION OF THE DEPARTMENT OF ENERGY

Mr. **Bartis**. My name is Jim Bartis. With me is Jack Siegle, who is handing out some of the reports. We are both from the Office of Policy, Planning, and Analysis within the Department.

Jack is Director of the Division of the Department and I, Director of the Division of Fossil Engineering.

Our report was undertaken within the Department by the staff of the Department, Jack, and my offices.

To better understand what was underlying the cost estimates that we were receiving from some earlier cost work done by both ICF and Technokron. I believe you just referred to one of those studies. The approach we used was a very straightforward approach. We asked ourselves what it costs to control the most cost effective—well, coals to reduce sulfur dioxide emissions.

What we did is we made an assumption. We looked at the control methods available to us and those are present coal switching, coal scrubbing, and coal cleaning.

We made the assumption that each of these methods is most cost effective when applied to the higher sulfur coals. This assumption has been borne out in a broad variety of studies.

What we did is look at the costs associated, the capital costs, operating costs associated with each of those control methods when as applied to all coals in the United States used by utilities greater than 3 percent sulfur content and all coals greater than 2 percent sulfur content.

What we found was that each of the control methods examined, scrubbing, cleaning, or switching, had roughly the same amount or same costs associated with it.

To make sure we understood the range of costs, we used ranges of input. So we took, for example, a broad range of scrubber costs. We tried to find the cheapest scrubber costs that anyone had put out and there was a serious estimate.

We looked at the higher costs for scrubbers. Liquid, can coal switching, we asked ourselves—what was the difference between the price of a low sulfur and a high sulfur coal?

What kind of range could we associate with that price? The same thing with coal cleaning.

What came out, we asked ourselves, how much would it cost in operating costs and capital costs to apply one of those technologies, each of those technologies to the extent that we could remove a million tons of SO_2 from existing sources.

We came up with ranges of operating and capital costs and combined these to obtain the present value and analyze costs. We multiplied that by the amount of reduction that we wanted. We obtained a range of reduction increments.

Once we obtained these results and these results are shown in this report, all the calculations and all the assumptions are in the report, in the appendix to the report. We went out of our way to do this and to show our assumptions and all our calculations, to remove any controversy concerning the quality of our estimates.

Once we did this, we looked at the earlier studies that had been done by ICF and Technokron through a joint DOE-EPA early analysis of acid rain and those study results are summarized in the appendix of the red report on page 20.

After we put them on a consistent financial basis and normalize them for the number of tons of SO_2 removed, we found out that the more cost-effective strategies looked at in these earlier studies, our numbers are consistent. They were consistent with the numbers we obtained.

Our cost figures for 10 million ton reduction came out to about $3.6 billion per year, 1980 dollars, analyzed costs and there is a range associated with this, between $2.7 and I think $4.3 billion.

The present value of that figure is about $55 billion and the 30-year costs are about $110 billion.

The interpretation that we give to our numbers are the minimum costs that we should anticipate for any legislative dealing with about—well, the numbers of just quoted a 10-million-ton-per-year reduction. They are minimum costs because we looked at the high sulfur coals in the system and we obtained large reductions from those coals.

We didn't look at 4-pound cap or 2-pound cap. So we really in essence used a very cost-effective approach. We are highly skeptical that any legislation or regulations to enforce such legislation will achieve those kind of economic efficiencies.

We also looked at the impact that particular reductions in costs would have on minor employment and displacement of coal. We found that for every million tons of SO_2 reduced between 20 and 25 million tons of high sulfur coal would be displaced by low sulfur, would have to be displaced by low sulfur coal if it were obtained by switching. So we didn't ask ourselves what portion of the 10 million tons would be obtained by switching. We cannot by using our methodology obtain that. We said for every million tons obtained by switching, that is the effect on coal production. We found that between 5,000 and 6,000, 400 miners would be effected for every million tons of coal with SO_2 reduced by coal switching.

We looked at our results, compared them to a number of other studies and we find our results consistent with these study results, especially when we put them on a consistent financial basis.

I would be glad to answer any questions later.

Mr. **Moore**. Why don't we go to Edison Electric Institute? George Freeman.

George, we cannot find any copies of this in the committee. I gather that they were supposed to have been delivered.

Mr. **Bartis**. Did you get some last night?

Mr. **Moore**. No; if we did, we don't know about it. We have one copy right here. We can make copies and distribute them later.

PRESENTATION OF EDISON ELECTRIC INSTITUTE

Mr. **Freeman**. I sent a number of you individual copies and we did send 25.

Let me quickly do two things: First, let me make a few general observations and then I will ask Jim Speyer to summarize the report which ICF prepared for us and then to respond to your specific questions. (The ICF report appears at p. 583.)

First, I simply would like to say that I thought that it would be helpful since we are talking about geographic regions to bring this map here and the green colors are bituminous coal; the yellow is lignite and you will see in the EPA report at the back of the paper that they just handed us and in the ICF report which they prepared for us.

Coal regions are the same. But I thought it would be helpful to simply reemphasize that northern Appalachia is the green part. Above the black pencil and essentially the Mason-Dixon Line of the high sulfur and low sulfur coal runs east and west through Charleston, W. Va.

Most of the coal above that line are high sulfur coal and most of the coal below that line are low sulfur coals. Central Appalachia is between that line and the Tennessee-Alabama border. Some of Appalachia is a euphemism for Alabama. This is the midwestern coal.

Then here are your far western coals as shown there.

One thing that would be helpful if any of you are interested, existing and new coal burning powerplants are shown all through the United States that are planned. These are the bigger circles and the original maps are existing plants and existing mines are shown on there.

So I think this map contains a lot of interesting information.

I would like to also say that picking up on EPA's new oil price that turns out to be $25 a barrel next year, if you back out inflation.

Last night I was talking to Prof. Fred Singer at the University of Virginia and some of you who have been following oil prices and may have seen his article in the Wall Street Journal and the New York Times over the past 2 or 3 years and he is the only person that has been consistently right on those oil prices.

He said they could even come down $20 a barrel. That is very important for several reasons.

Somewhere around that figure the economics of coal versus oil shift and so as you mandate greater and greater tonnages, you reach the point where at that oil price what happens is that rather than adding on scrubbers, first you try to make your tonnages by going to get low sulfur coal. That is the cheapest way to do it.

At high oil prices you don't consider oil as an alternative and further increasing the capacity of oil-fired plants. But around $20 to $25 you do and so you crank up all the oil capacity on the east coast and that power gets moved back into the Midwest before the Midwesterners start back to the scrubbers.

That is an important thing in light of the testimony you heard on Tuesday that the Rhode Island hypothesis, the testimony on Thursday of the Dartmouth professor, who has done the studies in New Hampshire and then it could be that that will make things really worse for the environment if oil-fired emissions really make a major contribution; in fact more of a contribution to acid precipitation in this area than long range SO_2 transport.

That is also backed up by a DOE study which I will make copies available. That is a very important key factor in the oil price.

Tonnages, absolute tonnages are the most important factor but also whether we have to offset for new sources both utility and nonutility emissions is important. That increases the tonnage by about 3 million tons so a 10-million ton rollback with our having to make offsets for new sources really is 13 million tons.

So I just wanted to emphasize what I thought were key factors in this overall analysis. So, Jim, will you explain what is in your report and answer Curtis' Roman VI questions?

Mr. SPEYER. The report that ICF was asked to do for Edison Electric Institute, some of you have copies. Unfortunately I guess not enough copies were sent up last night. The title of the report is "Summary of Acid Rain Analysis Undertaken by ICF for the Edison Electric Institute, National Wildlife Federation and the EPA."

What the purpose of this report was was to try to summarize the different proposals that we have done for these organizations.

Over the past year we probably analyzed over 50 different proposals. So clearly it was not possible to include all of these proposals in one document.

So we tried to just give a range of proposals and if you turn to figure 1 on page 2. There were eight proposals contained in this analysis, ranging from a reduction in forecast emissions from 1.7 million tons to 13.1 million tons.

Just briefly, the analyses can be divided into analyses of the metro bill. There were four of these; analyses conducted for EEI in

January, EEI in December and then the National Wildlife Federation Analysis which will be talked about later and then ICF analyzed what we felt was the OTA interpretation of the Mitchell bill.

These other analyses were primarily done for EPA last year and range from a 30-percent rollback down to a 10-percent rollback.

What I would like to do at the outset before getting into the details on how we got the emission reductions for the EEI analyses, I will concentrate today, given the limitations of time, just on alternatives 1 and 2, if there are questions on the other alternatives, I will be glad to answer those and we will be also sending up State-by-State detail on all of these analyses that will be part of appendix A.

The factors that I think you should keep in mind, they were mentioned somewhat by George, that determine what reduction you have to get in 1990 from utilities and what ultimately are the impacts on cost in coal production are really five factors.

Clearly the biggest, it is a specified level of reduction. A 10 million ton level reduction has a much bigger impact than a 5 million ton level reduction.

The second factor is, do you have to offset emissions from, well, is the reduction just from existing utilities or do you have to offset new emissions both from utility and nonutility sources?

The third factor are NO_x emission levels constrained not to exceed 1980 levels?

Related to this is what is the trading ratio in the Mitchell bill? It is 2 to 1, obviously different ratios will affect what the impact of the bill is.

The fourth factor is, will there be cost effective emission reductions from nitrogen oxide from utilities and/or cost effective emission reductions of SO_2 from industrial sources?

To the extent that you have these cost effective reductions, you will reduce the impacts of any bill.

Finally, is the question of, will interstate trading occur? As you will see, as you go through the report, the interstate trading at high levels of reduction saves you a lot, at low levels of reduction, it doesn't save you that much, just because you are not pushing the States to do that much.

Therefore, the savings are much less in interstate trading.

Turning now to table 1, just to explain how we derived the emission reductions that will be required in 1990 for the utilities under the Edison Electric Institute interpretations of the acid rain under the Mitchell bill, I would like to correct the typo, in the first column, if you go down the row, it says offset growth and utility emissions, So_2, there is an "X". It should be 1.5 million and for NO_x, insted of an "X", it should be 0.7.

The total is right. I apologize for that.

Looking first at alternative 1, which is the analyses that was done in January for EEI, a number of you have copies of that analyses. It is ICF Summary dated January 25. This was interpreted, the Mitchell bill was interpreted by EET to require a total of 10 million tons reduction of sulfur dioxide from stationary sources in the ARMS region.

NO_x emissions were also assumed to be limited to their 1980 levels and you had a two to one trading ratio.

So to implement the bill we first started with a 10 million ton required reduction in SO_2 and then looked at what are the projected growth in utility SO_2 emissions in the arms region and under the assumption we used we got 1.5 million tons projected under current EPA regulations.

So if you interpret the ceiling, you have to increase the reduction from 10 million to 11.5 million to offset that. We then looked at the growth of the utility NO_x emissions. It turned out that was 1.4 million tons, assuming a 2 to 1 trading ratio you would have to reduce SO_2 0.7 million tons to offset that growth.

Then we looked at the industrial emissions and industrial SO_2 emissions were projected to go up by 0.7 million and if you assumed all the reductions are taken from the utility sector, that is another 0.7 million that you have to reduce.

Finally, industrial NO_x emissions were projected to go up at 0.4 million, at a 2 to 1 trading ratio, that gives you 0.2 million additional ton reduction of SO_2.

So the total reduction would be 3.1 million tons, so you end up with a total of 13.1 million ton reduction from forecasted emissions if you interpret the Mitchell bill to be an absolute ceiling on total SO_2 and NO_x emissions in the ARMS region from stationary sources and if you assume there are no cost-effective emission reductions from utility NO_x and from industrialSO_2.

To look at the sensitivity of this result, to what happens if you assume cost-effective reductions EEI also had us run an analysis alternative 2 where you said, what could you get in terms of reductions from utility NO_x and from industrial SO_2.

As you can see there, utility nitrogen oxides you could get a credit of 0.8 million tons and that assumes you reduced to emissions by 1.6 million tons with a 2.1 trading ratio, gives you a 0.8 credit.

Industrial SO_2 could be reduced by 0.3 million tons in a cost effective way so that that gives you only a 12 million ton reduction with that interpretation of the Mitchell bill.

The other analysis on this page we will nto talk about at the moment except if you want in terms of questions. A number of these will be covered by speakers that will follow me.

Turning now to what the impacts are in terms of cost impacts were for the EEI runs, turn to table 2 on page 9.

As you can see, the annualized costs of alternative 1, a 13.1 million ton reduction, is $6.9 million.

Looking at alternative 2, you see that the costs range from $4.3 to $5.4 billion and this is where you see that if interstate trading is politically feasible at these high levels of reductions could save, say, $ 1 billion a year in 1990.

I think it is important to note that even the runs without interstate trading, assume completely efficient allocation of the emission reduction liability within the States, namely if for the State of Ohio, all the utilities in Ohio would trade the liabilities among themselves to get the least cost solution or it would be allocated by the State in that way.

One thing on these other alternatives which time does not permit me to get into in detail, you can see at lower levels of reduction, as I said in the beginning, there is less potential savings from interstate trading. that is basically because you are imposing less of a reduction requirement on the States. They really don't have to go to the interstate trading for savings.

In terms of electricity rate impacts, these vary considerably across the States and it would vary even more if you took the capital system variation.

Looking down in terms. Alternative 1, the rate impacts go from less than 1 percent in some States to 23.3 percent in a particular State in the arms region and for alternative 2, the maximum is 17.6 and a minimum is less than 1 percent.

The State-by-State details will be included in the appendices and in the January 25 document, you do have and a number of you have seen the State-by-State impacts with EEI alternative No. 1.

A caveat here about these electricity rate impacts, these represent increases in annualized costs which in effect are roughly equivalent to what the average rate impact is over this period.

A number of the analyses that the utilities will be presenting, I think concentrate on first year rate impacts which, if you assume that most of the investment in the scrubbers is made in the late 1980's, first year rate impacts would be higher than the rate impacts than presented here by about a factor of 2, however rate impacts in the later part of the nineties would be lower.

So this lower rate impact, it is important to realize, is in a sense an average rate impact over, say, the decade of the nineties.

Turning now to the coal production impacts which is table 3 on page 12, the results here are much the same as what EPA reported.

Looking at the EEI alternatives 1 and 2, you can see that there is a reduction in production in the high sulfur regions, namely, northern Appalachia and the Midwest and an increase in production in the low-sulfur regions which are central Appalachia and the West. This is simply because it is more cost effective to generally go to low-sulfur coal than to install scrubbers on high-sulfur coal.

We have similar conclusions to EPA that if you look at alternatives 1 and 2, you get the production decreasing below actual 1980 levels. So the production in 1990 under either alternative 1 or 2 would be below the actual production in 1980 in these regions.

There is really only two ways to mitigate these coal production impacts. One is you stretch out the rollback, most of the rollback, to the post-1995 or post-2000 period and give new technologies, fluidized bed combustion, combined cycle gasifiers, an opportunity to make high-sulfur coal more cost effective. You need both of those elements, namely you stretch it out and these new technologies come in and prove to be cost effective. The other way to reduce it would be to impose a requirement that you have to use local coal. This has two effects. One, it drives up the cost, and two, given the experience of section 125 of the Clean Air Act, it is questionable, the effectiveness of such a provision. That is something that you all are in a much better position to evaluate than we are.

But those are really the only ways to mitigate these coal production impacts in the high sulfur region.

I think just a final point, before I conclude, is that looking at this report, I think, will help you make general conclusions as to what happens as you move from lower levels of reduction to higher levels of reduction. However, if you try to compare these reports at a State detail you run into the problem that the runs we made for EPA last year, for the National Wildlife Federation, and for EEI, have different assumptions about electricity growth rates and scrubber costs. That does not really affect the overall results when you are looking at the broad regional level and the national level, but when you want to look at the specific State of Ohio to see exactly what is the difference between the National Wildlife report and the EEI report, I think you have to be very careful at that level. I would caution you only to look at it more in terms of aggregated states, rather than on the State detail.

The other things is that this report really did not have a chance to get into all the implications of differently built schemes and how they affect total costs. Just briefly, the three approaches that have been thrown out so far in terms of the debate, one is the equal rollback approach. You just reduce across the board x percent. This tends to increase the impact somewhat in New England and reduce the impacts in the Midwest.

The other approach has been the emission cap. Every plant can't go above some level, 2 pounds per million Btu, SO_2, 4 pounds, whatever. This tends to be the least efficient approach because plants cannot trade with each other. You could rectify that by saying plants would be allowed to trade with each other, one plant could, say, reduce its emissions down to 1.5 pounds, the other plant could go up to 2.5 pounds, assuming they were the same size. For me, it seems simpler just to have a rollback.

The final approach is one like the Mitchell bill, excess emissions above some level, whether it is 1.2 or whatever. This also has the impact—well, this has the impact of lowering the impact in New England, which already has low emissions and increasing the impact in the Midwest, which tends to have higher emissions.

These initial rollback schemes cannot affect how the costs are allocated across the States.

Mr. **Freeman**. Jim, we were supposed to address these questions. In view of the time situation, I think most of the assumptions you made for the three different groups are set forth in your report and answer virtually all of the questions. If in the interest of time you want us to point those out, we will.

We will also, for your convenience, ask Jim to go by and at least, for the three different analyses or four different analyses of the Mitchell bill, give the assumptions, give you another piece of paper in the next day or two at the same time we send up our State-by-State analysis that specifically goes down your thing point by point.

Mr. **Moore**. I suspect that some of these questions listed on the agenda will be answered during the course of the question and answer period. But all of the institutions appearing here today are asked to respond specifically to each of these questions in writing during the course of the next several days, so that we have a written record of answers to each of these points.

Mr. **Freeman**. I will say since Jim mentioned it, at the end of this meeting, we will give you the papers which we have prepared for tomorrow's discussion, which are the individual system analyses, so that you can review them.

Let me just emphasize one thing. That is the unreliability of system or State average figures to show a rate impact.

I will illustrate by simply focusing. There are four basic utilities in Illinois. Commonwealth Edison is by far the biggest, it is in the northern part of the State. It would be very slightly impacted by this legislation because it has a substantial amount of nuclear capacity; and relatively a small amount of coal capacity. In fact, they could have a higher percent of nuclear capacity than any utility in the United States. Similarly, Central Illinois, which is down in here, has a nuclear plant that is about to come on line and again it would be less severely impacted, though I think their system estimate are around 20 percent increase in rate.

Union Electric, which operates both in Missouri and Illinois, would be quite impacted because it has some coal-fired plants in Illinois and has only coal-fired plants. Similarly central Illinois, which is totally on coal capacity. So the variation among those systems could range from 2 or 3 percent to 35 or 40 percent if we had some way of modeling through these macro models system costs. We will talk about those tomorrow.

We have done them on a system-by-system basis, not using models, but just figures.

Mr. MOORE. Wildlife Federation/National Clean Air Coalition.

PRESENTATION OF NATIONAL WILDLIFE FEDERATION/ NATIONAL CLEAN AIR COALITION

Mr. HAWKINS. The three pieces of paper that will be making their way around to you, are a summary of what I am going to tell you; a 2-page highlights of comparative electricity rates which you may have seen before, and then a copy of the study, a full copy of the study that was done for us by ICF.

I didn't introduce myself. I am David Hawkins. I am representing the coalition.

Our study was a follow up on the initial study done for EPA and the Department of Energy by ICF. That initial study estimated the costs of a 5- to 7-million roll back in sulfur oxide and it also examined some options for controlling NO_x emissions as well.

The Clean Air Coalition retained ICF to examine the costs of a 10-million ton reduction in sulfur oxides in the same geographic region; that is, in the 31-State eastern U.S. region and using the same model and the same assumptions as had been used in the earlier EPA-DOE analysis.

The highlights of the results are in the thickest of the documents that you are receiving. They are in table 1 on page 10 of that document, for your reference.

What did we do? We asked ICF to analyze the costs of reducing emissions by 10-million tons from the levels which would otherwise have occurred in the future in two different years, in 1990, and in the year 2000. I say it in that fairly awkward fashion to distinguish it from a 10-million ton reduction from today's emissions.

It is different in two respects. First, reductions that will occur anyway without acid rain control program between now and 1990 are not counted as part of the 10-million ton reduction program; second, increases that would occur anyway without any new program as a result of increased fuel use, either in existing plants or in new plants are not counted against the 10-million ton reduction program and are not required to be offset. You can see that those two factors have a slightly compensating effect on other, but the net result is to have a reduction from today's levels in 1990 of something less than 10-million tons.

I have put a number down here, estimating it as something like 8.5 to 8.9 million tons reduction in 1990 compared to today's 1980 emissions.

And by the year 2000, since there is more growth, the reduction will be something less than that again.

I put down the numbers 8.2 to 8.6.

So that was the basic thing we asked them to examine and we had them then examine four alternative allocation approaches.

The first was the national, so-called national least cost allocation, where the emission reductions were assumed to occur in the facilities where it was cheapest for them to occur in the States in which those facilities were located paid for them.

The second, this is the first typo on this thing, that should be on page 2, item 2, 1.2 pounds, not rounds, and 30, not 20; 1.2 pound 30-day average. That is an approach similar to the approach in the latest EPA analysis as well as the one in the Mitchell bill; that is, the allocation is based on state's share of emissions which are in excess of a figure 1.2 pounds.

The third has been mentioned already; that is, an equal percentage reduction. Everybody reduces in the 31 States by an equal percentage reduction sufficient to make up a 10-million ton reduction. That works out to be 56.2 percent.

The fourth is one that is, I suppose closer than anything else to the Moynihan bill, but not the same as the Moynihan bill, and that is one that loads a little more cost onto the largest emitters by allocating the shares according to an 85-percent control reduction on the sources emitting more than 100,000 tons and then allocation based on the excess over 1.7 pounds per million Btu for all the rest of the utility sources located in that State.

Interstate trading was allowed in all of these. The results, as have been mentioned, I will go over them quickly, is that the 10-million-ton program would have analyzed costs of $2.4 billion in 1990; $3.4 billion in the year 2000, which amounts to an average rate increase in eastern electrical rates of 1.9 percent in the year 1990, 1.7 percent in the year 2000.

The range of State rate increases has been mentioned. It is a function of the allocation technique chosen first of all under the Mitchell type allocation technique. The range is from something of a minus 4 percent in the Greater New York Metropolitan area, in New Jersey and eastern Pennsylvania to a plus 7.4 percent in Indiana.

The coal shifts, I should mention that the States receiving the highest rate increase in this analysis and, I believe, in the others, would be projected to have lower electrical rates in the projection, in the future than would the eastern seaboard States after that rate increase had been imposed.

Coal shifts there are similar results in our analysis to everyone else's. Reduction in production in northern Appalachia and in the

Midwest, increases in production in central Appalachia, and the West. Our analysis showed that in 1990 you would have reductions that actually went below 1979 production levels in three States, Ohio, Pennsylvania, and Illinois, with 10-percent reductions in Pennsylvania, and Illinois, with 10-percent reductions in Pennsylvania, 18-percent reductions in Ohio, and 22-percent reductions in Illinois.

Using the growth assumptions that were done for EPA, DOE and ourselves at that time, these reductions are predicted to disappear by the year—sometime between 1990 and the year 2000. With lower growth rates, the disappearance of those drops in production are less certain and as is shown by the most recent EPA analysis, actually that did not, we don't have figures from EPA, yet I guess, on anything beyond 1990. But obviously the lower the growth rate, the less of an increase that you will see between now and the year 2000 in total production in those areas.

I have mentioned the key assumptions. And, as I say, we asked that they be identical in all respects to the EPA-DOE assumptions. ICF, on its own initiative, made some technical changes relating to oil product prices by sulfur content, coal transportation rates, and treatment of nuclear capacity. We did not ask ICF to analyze the NO_x for SO_x trades for the simple reason we didn't have the money to pay for it.

We didn't ask them to analyze the cost savings associated from getting reductions from industrial sources. The modeling analysis that was done assumed all the sulfur oxide reductions would come from utilities. Again, we did not have the money to pay for it. That is why we didn't ask for it to be done.

Our assumption that there would be interstate trading was based on our awareness of the current utility practice, which is not universal, but certainly is common of multistate, multicompany consortia for owning and operating generating stations as well as interstate sales of electricity.

The last two pages attempt to answer the last question on the staff's list of questions; that is, the comparison of the assumption is, base case assumptions used in our analysis with the analysis done for CBO. I won't go through all of these things. I would highlight a few items.

The scrubber cost assumptions in our analysis are 10 to 20 percent less than the scrubber cost assumptions in the CBO analysis. The inflation rate in our analysis was 9 percent versus the CBO analysis of 8 percent. So that in the year 2000, those two factors will compensate largely for each other.

The analysis that was done for EPA, DOE and ourselves assumed a much higher growth rate in industrial coal use than have more recent analyses as is evident from the table on the next to the last page with a difference in the year 2000, for example, of 410 millions tons of industrial coal use in our analysis versus 225 in the CBO analysis.

That is one of the factors I was pointing to that would obviously make a difference in the increase in coal production in various States. The coal exports are similar. Ours tend to be a little lower for steam coal and a little higher for other coal.

The other things I will tough on very briefly before winding up is attempt to run down orally and I will give you this in writing later, answers to some of these questions just so we will have them in mind.

In terms of the method, it was the arms region, least cost basis and the base line years were 1990 and 2000. We did not assume a cap either on existing sources or new sources. So there was no requirement to be offset.

I mentioned that. We did not assume NO_x for SO_2 trades, no money to pay for it; we didn't assume industrial emission trades, again no money to pay for it.

There was no absolute emission ceilings imposed. The State-by-State reductions estimates are provided in table 11 of this thickest document. The analysis assumed that all of the reductions would be accomplished by utilities even though all of the legislative proposals would permit industry reductions to be credited and, again, the reason was we didn't have the money to pay for that extra analysis.

Item D, how much comes from SO_2 emissions in each State. We didn't have ICF analyze that for us, how much comes from utilities in each State. But those analyses I know are available. OTA has had them done by, I guess, Peckham and I don't know if ICF has a separate set of those State-by-State emission inventories for utilities or not.

We didn't calculate NO_x emissions in this analysis, again no money. We chose our reduction alternative to do the next level of reduction in terms of total tons that was greater than anything that had been previously analyzed but deliberately less than what we perceived to be what the scientific community would recommend as needed.

We knew we were going to have money to do only one of these analyses. We wanted to come in with a program that couldn't be argued against on the grounds that it was obviously more than what was needed. So that is why we chose the 10-million ton reduction to be analyzed.

Most of the other questions I have already answered on page 1.

The total average cost per ton of sulfur is $244 in 1990 and $344 in the year 2000. That is just the annualized cost divided by the 10 million tons.

The scrubber costs are all detailed in the scenario specifications document done for EPA and they are also summarized in the attachment that I gave you.

The EPA study that we followed up on by the way consists of these four documents. I understand Paul's reluctance to make 30 copies of all of it. But there are four documents and they are available and the scenario specifications document was probably the important one to have in addition to the executive summary.

The other ones are the draft report and then the regional summaries which is 2 inches of computer printouts.

I won't take any more time right now to summarize the answers to all of these questions. They are all answered in the scenario specifications document and I will provide a written summary of them.

Mr. MOORE. Next, OTA.

PRESENTATION OF THE OFFICE OF TECHNOLOGY ASSESSMENT

Mr. **Trumble**. My two pages are slightly shorter than Dave's two pages, both well over two pages.

What I have tried to do here is cut down some testimony that we delivered last October on the costs of the Mitchell and the Moynihan bill and then include a few new figures to go along with the discussions this morning.

I guess if you could just follow along with some of the tables, reserve the text for later, a few points that I wanted to make.

First of all we have had some discussion this morning about emissions, current emissions on which most of these proposals are based.

Table 1 of my briefing memo has our estimates of current eastern sulfur dioxide emissions, 1980 emissions and on the right-hand column we have a list of the percents of those emissions from utilities.

Each of these bills concentrates on allocation formulas specified as some function of utility emissions. Utlility emissions are about 70 percent of emissions in the Eastern 31 States. There as quite a variability, range of variability from State to State.

As Jim Speyer pointed out, some of the major differences between the cost estimates that you see, if you turn to table 2 now are the sulfur dioxide emissions reductions required by or interpreted as required by the various bills by the various analysts.

As we interpret the Mitchell bill, it requires that the amount of sulfur dioxide and nitrogen oxides emitted in the 31 State region does not exceed the amount of each of these pollutants emitted from the region as of January 1, 1981.

However, we interpret that the 10 million tons is a reduction of SO_2 is a one-time reduction; that is, new source growth need not be offset by additional emission reductions.

In addition to that 10 million ton reduction, not counting new source growth, current emissions in the Eastern 31 States we estimate are about 1.5 million, 1.4, 1.5 million tons out of complince with State implementation plans. So that the net reductions that we charge to the Mitchell bill rather than to other laws and regulations is about 8.6 million tons.

Table 3 are our estimates of the reductions required by the Moynihan bill. We estimate that the reductions specified by this bill are about 6.7 million tons. However, because of the wording of the Moynihan bill, we interpret that as to not include the emissions that are currently out of compliance so that even though we in our cost estimates charge only emissions reductions for 6.7 million tons, the emission reductions after the Moynihan bill is acutally implemented would be about 8.2 million tons.

Let me move quickly to figure 1, skip a couple of pages.

What we tried to do in this graph is similar to a graph in the DOE report that was handed out, was our estimates of the costs of various reductions in emissions on this chart we have displayed a horizontal axis, the sulfur dioxide emissions reductions in million of tons per year; versus the additional control costs. These are in billion dollars per year.

In 1979, dollars to get to current dollars, add somewhere around 20 to 25 percent, multiply by about 1.2 to 3, something like that.

On this graph we have several emissions or several allocation formulas.

Let me just start with the Mitchell bill which is not quite the highest reduction. It is marked with two black squares. Our estimates for the costs of the Mitchell bill range from $3.1 to $4.1 billion per year.

Moving down to about 8.2 million ton reduction, our estimates for the Moynihan bill are about $2.2 to $2.6 billion per year.

Again, these costs are first year annualized costs and they are in 1979 dollars. The costs for or these estimates do not include the costs for emissions reductions required under current law.

The lower estimate—that is, the $3.3 billion for the Mitchell bill, the $2.2 billion for the Moynihan bill—assumes that each State will choose the most cost-effective way of meeting the required emissions reductions. This might occur by some intrastate trading or by a State requiring emissions reductions from those plants that can reduce emissions most cost effectively.

No interstate trading occurs in this scenario run. The upper estimate, $4.1 billion for the Mitchell bill, $2.6 billion for the Moynihan bill, assumes that each State would achieve the required reductions by assuming uniform emission ceilings on utility plants; that is, any plant that is in excess of a specified emission rate would have to reduce down to that rate.

It is obviously a more expensive approach. It does not take advantage of potential cost savings.

As well on this figure 1, we have displayed a range of estimates for several different emission limits. A 4-pound per million, SO_2 per million Btu, 3 pound, 2.5, 2, 1.5, 1.2, and 1.

The solid curves that you see on the graph is our estimate of the ranges going from a least cost approach or an efficient trading approach, to a plant by plant, we feel that the cost would be somewhere in this range, depending upon inefficiencies in the market and so on.

Notice on this graph that it starts out very low at about 2 million tons reduction. The reason for that is we don't charge out the first 1½-million tons which again is our estimate of how far out of compliance with State implementation plans emissions in the Eastern United States currently are.

At this point, let me say that so far we have heard, I think, exclusively from model runs prepared by UCF. We do not use the ICF model in our analyses. Our estimates, I believe, are slightly higher than most of the ICF analyses. We use a model called the air test model. This was modified from a larger model that was used in several previous assessments, including some work for the new source performance standards review, the Ohio River Basin energy or the ORB study and as well as some of the acid rain mitigation studies sponsored by EPA and DOE.

The model estimates the cost of SO_2 emission reductions for each of about 2,000 boilers and about 900 utility plants.

Like the ICF analysis, the model assumes that the least expensive option will be chosen at a plant or for a boiler, that is fuel switching, fuel blending, scrubbers, or some combination.

The premium paid for lower sulfur fuels is estimated by State. Unlike the ICF model, we use historical data to estimate the premium for cleaner fuel. We make no assumptions about the future changes in price or the effects of competition.

We assume that the best indicator of the price that will be paid is the price that has been historically paid and we can vary those accordingly.

Scrubber costs are very similar to those used by the ICF model and we have some of these listed in the testimony as well.

I would like to move to the next figure in the testimony which should be a map.

Figure 2, percent increase in electric rates.

I have resisted to this point releasing some State-by-State estimates of some increases in electric rates. The major reason I have done so as Jim Speyer mentioned is these estimates are much better as regional estimates when you get down to some of the smaller States that just involve a few plants or a few boilers.

We use average cost and, therefore, the model estimates become less reliable.

What I tried to do on this map is to break out the percent increase in electric rates, in different ranges of percent increase. These are not equal ranges, as you can see, from the key on the right-hand side. I guess the table or the graph is pretty much self-evident. The highest rates of increase are in Missouri, in Indiana, Kentucky, Tennessee, West Virgina, The lowest are in some of the New England States, Louisiana, Arkansas, Iowa, much of these rate increases are, of course, a function of not only a quantity of emissions but the cost of emission reductions in each State and because these are presented as percent increases, they are also a function of what is currently being paid for electricity in the 31 States.

So if you flip to the next page we try to show the effect of these percent increases in rates. What we have done here is we have taken the ranking within the 31 States and the District of Columbia, that is, why there are 32 numbers in the 31 States, we have taken the ranking before the Mitchell bill and after the Mitchell bill; that is, with these percent increases in cost from the previous map shown.

We have used as a basis 1979 electricity rates and 1979 percent increases so that our data were consistent. So there may be some slight changes in rank.

You can see that even though New York, for example, on the previous graph is in the lowest percent rate increase, somewhere between 0 to 2 percent before the imposition of the Michell bill, it would have the highest electricity rates, No. 1, and after the imposition of the Mitchell bill, it would have highest.

Another example or examples, Kentucky and Tennessee, which have relatively high percent increases in electric rates, somewhere in the range of 6 to 9 percent for Tennessee and 9 to 12 percent for Kentucky, there still before and after the Mitchell bill somewhere down around rank, 30, 31, 32 in electricity rates within the region.

I would like to just make a couple of comments as to what we have considered in our analyses and what we have not.

First of all, for all of these analyses, these are model based estimates. They are necessarily approximations of reality. As well, we couldn't in our model fully incorporate the provisions for flexibility in achieving the emissions reductions specified in both the Mitchell and Moynihan bills. We only considered sulfur dioxide emissions though the bill specifies a substitution of 2 tons of nitrogen oxides for 1 ton of sulfur dioxide, we did not include this, first of all, we don't believe that the current inventories of nitrogen oxides are presently reliable enough; that is, one could set up a trade but one doesn't know what we are trading from, and second of all, we are not certain that we know the costs of nitrogen oxide control well enough to go ahead with this type of anaysis.

I would see it worthwhile as a separate exercise. We consider only utility sulfur dioxide emissions reductions. We don't include in the analysis reductions obtained from nonutility industries. Again, part of the reason for this is that the data base that exists on industries other than the utility industry is rather poor.

Maybe Paul Stopman from EPA would say some words about that later. But we have had tremendous problems in trying to figure out not only the emission rates from various industrial sources, but the total emissions in the Eastern United States.

Again, one of the assumptions is, we analyze only existing utilities as we interpret the bill. New source growth does not have to be traded from existing sources. And last we consider only a finite list of control alternatives. These do include fuel use changes, coal washing, wet and dry scrubbers but we don't include emissions reductions approaches such as least emissions dispatch; that is, selective use of lower emitting plants or the effects of new technologies which may be available within a decade or two.

There is further documentation in the handout as some of the control costs and I guess I will just stop there.

Mr. MOORE. Peabody?

PRESENTATION OF PEABODY COAL

Mr. FARRAND. My name is Chris Farrand.

Last October we appeared before the committee to present some analyses that we had done of the Mitchell bill at that point. Based on one primary assumption, that the first and most extensive response of the utility sector to this requirement, to the 10-million-ton reduction requirement would be to switch fuels. We did this for two reasons.

One, we know from our own experience that this will be the first and most extensive response that individual utilities would look at; and, second, when we got into it we did not know the extent to which fuels would have to be substituted. We thought at the time that there was a chance that you could achieve the entire requirement through fuel switching. But probably that is not the case.

You are being handed three documents. One is a summary of the remarks I will make today. The second is a copy of our testimony of last October, which includes the results of our analysis and a State-by-State breakdown.

The third is an offcolor comparison of a number of economic studies that we have prepared and summarized.

The fuel switching assumption or scenario that we used will lead to ultimate consumer costs that are going to be on the conservative side if you believe that fuel switching is the least-cost approach. However, they are on the high side as far as coal displacement and employment impacts are concerned.

The analysis that we did does not account for the effects of economic growth during the intervening years to the 1990 requirement. So we used a flat 10, and not a 13-million-ton reduction.

Obviously, if you interpret the bill in the other fashion, you will end up with higher numbers than we arrived at.

Second, no attempt was made to account for the effects of inflation. We used our cost estimates all in 1980 dollars.

Third, we made no measurement of the effects of a surge in demand for acceptable or low-sulfur fuels. We have some evidence that there is a sensitivity factor of about 1 to 3 to 5 in the demand for low-sulfur fuels. In essence what we did is classify two commodities. One is an acceptable fuel and the other is an unacceptable fuel. The theory is if you increase the damand for low-sulfur coal, you are going to drive the price of that commodity up.

We made no accounting for that. If you did, it has a very significant impact on the cost of the bill for two reasons. In our analysis the total fuel switching you end up increasing the demand for low-sulfur or acceptable fuel, coal by better that 100 percent across the eastern part of the country.

In the ICF analysis, you increase it by about 50 percent.

We assume that if you increased the price as a result of that increased demand, you had a demand price increase of 10 percent, then the cost of this bill escalates by about 40 percent or better. So it is a very significant factor that we did not account for.

Fourth, we assumed that wherever a low sulfur fuel was substituted, it was of comparable Btu value. If not, if it is a lower Btu value, then you have to buy more tons and you pay for it on a cost-per-ton basis. So that would have again an impact on your final cost.

We also did not assume that where low-sulfur, low-Btu western coal was the substitute fuel, that we did not account for the boiler modifications and particulate control emission equipment that you would have to add on.

Ours was an annualized fuel cost differential analysis, not a capital cost analysis. There is one other aspect of that.

In switching fuels or blending, you have to add blending facilities at you plant. You are taking *x* amount of tons of low sulfur and *x* amount of tons of high sulfur to blend to get to what is an acceptable limit. You have to have blending facilities. We do not account for that as well.

Our analysis calculates the amount of acceptable coal at the precise blending level with no margin of safety and obviously you get a different kind of differential or total cost if you build in a margin of safety in your blending system, which is the normal practice of the utilities.

Finally, we made no assumption, something which was very dear to our hearts, and that is if you reduce demand for high-sulfur coal at a particular plant from a particular mine, which is the way coal is sold, and you cut the demand for that coal, and substitute for blending purposes coal from another source, we had no effect on the economics of reducing the production of an individual mine.

If you take a million-ton mine and reduce its production by half, the economics are such that you probably have to close the mine. Obviously, that production is going to be made up for somewhere else. But that is at least to us in the business a very severe economic effect. We did not account for that.

Let me back up a little bit. Not only did we not use the ICF model, we did not use any model at all.

Our analysis is based on the actual delivered price of coal in 1980 to individual plants. For each State we got a fuel cost differential, a unit cost differential for high sulfur coal delivered in that State and low sulfur coal delivered in that State. Where there was not empirical data in that State for either of those two commodities, we used an adjacent State. In the testimony of last October, we indicate what we did for each of the States where we had to go outside to get empirical data. So it is 1980, actual delivered cost differential.

On an aggregate for the 31-State area, the fuel cost differential for coal is about $10.16 roughly. It varies widely from States. I do have figures, penciled figures for individual States if anyone is interested in it.

As a result of this kind of analysis and the approach that we used, we end up with a 1980 dollar annualized cost in 1990 of $3.2 billion. If we were to inflate that to the current time, to early 1982, it would be about $4 billion annually.

From the standpoint of the reduction backout or reduction dislocation and the resulting employment impacts, we found we are going to displace about 307 million tons. That is displaced within a State and within the entire region.

So that as production at individual mines are going to lose, it is going to be made up for presumably somewhere else. It is going to be made up for, may be made up for in large numbers, depending on the Btu equalization.

As a result, it is 307 million tons of displaced coal, annual coal. It is worth about $9 billion. From an employment impact, we found that the effects would be about 75,000 mining jobs.

In our October analysis, we used a standard multiplier of 1.5 to get the indirect job loss. However, subsequent to that, we developed a multiplier using some data that the Department of Commerce has used in Ohio which came out to about 3.3. We rounded it off to 3. Adding a multiplier of 3.0, the total job loss is approximately 300,000.

I shouldn't say loss. Let me clarify that, job placement is about 300,000 jobs. Obviously, the principal losses occur in Illinois, Kentucky, Indiana, Ohio, northern West Virginia, to lesser degrees in Pennsylvania, Missouri. I should say western Kentucky and we did not do any analysis of the gains, but the presumption is they would be made in three States, which would be southern West Virgina, eastern Kentucky, and Virginia.

I would be happy to go through and answer any questions.

There are a couple of other assumptions that we were asked about. In the two-page statement No. 1 we did not assume any tradeoff NO_x and SO_2. One we used a nontechnology approach in toto in our analysis and NO_x reductions require technology and, No. 2, at the time, and within the time constraints we had to develop that analysis, we did not have the sufficient NO_x in which to do any kind of tradeoff.

Second, while we did not assume interstate trading to get emission reductions, we did assume at least indirectly trading within a State. We did that because our method of analysis arrives at the quota of reduction required in an individual State and the amount of coal that we have to back out and the quality of the substitute coal that would have to be put in. That gets averaged out per State.

From that we arrive at the tons and from the empirical data we arrive at the unit cost differential and by multiplying it we end up with the State-by-State number and we did this by individual States and arrived at our aggregate by simply adding the State cost differentials.

I would be happly to answer any questions later on.

Mr. MOORE. United Mine Workers?

PRESENTATION OF UNITED MINE WORKERS

Ms. KUCHAR. I am Patty Kuchar, research analyst from the United Mine Workers.

When we tried to assess the impact of acid rain bills, we took Peabody Coal Co.'s study, their determination of where coal would be displaced for 1706, it was a 12-State area. And on the basis of those displacement figures we tried to list the employment and ecomomic impacts in those areas. We essentially did the same thing Peabody did, but we did it with more State-specific data.

We took the individual contribution of coal mine employees and office employees on a State-by-State basis. Those figures are tabulated by the Mine Safety and Health Administration each year and because obviously if there is going to be displacement, the mine is closed, there is going to be not only coal miners, but office workers associated with that.

On the basis of that, this is attachment A. We determined what the coal mining industry job displacement would be and tried to figure that out on the basis of—what we did then was we tried to figure our what the average salary would be for a coal mining employee and also for the office worker again done by the same ways. We then took the Bureau of Economic Analysis data from the Department of Commerce. They have county-by-country and State-by-State data on the salaries or economic benefits, whatever you care to call them, for each sector in a county and a State economy.

So our multiplier is what effect any decrease in employment in the basic sector would have on the nonbasic sector, and it was calculated for each State, and you would come up with the losses as a result of that multiplier, and then you just add the two together and you get the total economic losses.

We did not for 1706 and 1709.

The way we came up with our coal displacement in 1709, we used the comparison data between the two bills, assuming that Peabody's analysis of the coal displacement is correct, that a certain emissions reduction is going to displace so much under 1706, we arrived at a factor according to OTA analysis that emissions reduction would have so much percentage in each State per 1706 and 1709, we came up with the factor and came up with the numbers of, the tonnage displaced for the States in 1709.

Again, we did the same analysis.

We feel that the impact is going to be very severe on employment, especially in Illinois and the same conclusions that everybody seems to have arrived at, in Illinois, in Pennsylvania, in Ohio. We looked at it and we looked at the unemployment we have right now in the coal mining industry. We currently have almost 30,000 miners unemployed. Those are just UMWA miners and no way to tabulate non-UMWA miners at the moment. We feel this is just going to be a devastating effect, not only to those people, but to those communities.

Our analysis did not look at, as Peabody's did not, the gains. The reason we did not, we felt that you had to make some pretty unsubstantiated assumptions about where the gains would occur. At any rate, we are concerned for wherever those gains are going to be taking place, there is obviously going to be some disruption there, too, because I think you are going to find that there is going to be unanticipated much growth, people living in shantytowns, trailer parks, the same thing that occurred a long time ago in the eastern part of the country.

I think you have to look at that, too, when you look at the assessments in terms of gains. You have to also look at what will happen to the price of low-sulfur coal, the coal industry feels that cargo preference would kill the export market. We feel if the price of low-sulfur coal goes up, add to that the transportation costs that will have a devasting effect, too, on the export market.

We looked at other studies when we did our analysis. ICF seems to be the one that everybody is using. We felt that there were certain erroneous assumptions on the part of ICF, namely, that they would use the least cost authorization model.

ICF assumes that there is going to be an equal or a mix of fuel switching, blending, and use of scrubbers. A major utility in Illinois has stated flatly that they will not use scrubbers unless forced to.

Indiana, Michigan, went to court to try to become exempt and did become exempt for their Rockport plant that they are building from the 1979 SPS. They are planning to use low-sulfur coal at about $23 a ton in Indiana. They are planning to ship Wyoming coal which in Wyoming is about $10 a ton to Indiana at the cost of $42 a ton. So we believe that that assumption, what you have to answer is least cost to whom?

Another assumption that we felt was somewhat inaccurate on the part of ICF was their assumption that all existing long-term contracts could not be broken. There is a certain provision called the force majeure provision whereby if coal supply contracts do not meet environmental requirements they can in fact be broken.

I think in drafting any legislation that you have to be concerned about the employment impacts. You have to be concerned about what is going to happen to these areas regardless of whether they are areas that are going to lose or whether they are going to gain.

I would be happy to answer any questions.

Mr. MOORE. I think that completes the presentations.

I would like to, before opening it up to questions per se, clarify one thing. As I understand it, I will refer to a computer model as a black box, we have three institutions here which did not use a black box per se, and they are the Department of Energy, Peabody, and the United Mine Workers. Is that correct? Then we have three other institutions here that used the same black box; namely, that one operated by ICF, though the assumptions of those three institutions varied somewhat and those three are EPA, EEI, and the National Wildlife Federation/Clean Air Coalition; is that correct? Then finally, we have one institution which used the OTA black box and that is OTA itself; is that right?

OK.

I wanted to make that clear. I wanted to clarify that.

Mr. **Freeman**. Before you get into questions, I did get extra copies.

Mr. **Moore**. While George is completing the distribution of the Edison Electric Institute materials, let me clarify again that we would like to assure that first we will be receiving written responses to each of the items listed on the two-page agenda and second, that we will be receiving copies of other studies which each of you might have done or had done.

We would like those, if possible, by close of business on Friday, so that we can start out with all of our information in hand Monday morning working on the subject.

Jon Jewett has to leave in a couple of minutes, so we will toss it over to him. We will let him have the first question.

Mr. **Jewett**.[1] My first question is addressed to principally EPA and to ICF, and I am curious as to why you did not include any transaction costs in your estimate and how realistic is it to assume a frictionless economic system.

As I understand it, what you are saying is the reductions would be made in the most theoretically efficient way. Is that close enough to reality? Do you think that you don't need to make any assumption for transaction costs?

Mr. **Wagner**. Can you suggest a way I could assume how to get transactions costs? The problem we have is that we have a model that essentially imitates a perfect market and in real life we know markets aren't perfect and we end up actually with this. We find that we have to step in and limit the model, to try to build more coal capacity than people are actually building, for example.

Since we can't really include the behaviour of the Public Utility Commission, which is one of the reasons a lot of the capacity isn't getting built, we step in and essentially require capacity based on sort of what the model says in expectations.

The transactions costs are probably going to be fairly important. At the moment I certainly don't have a really good way to estimate how that would be and I would suggest that what we have is a good estimate of a lower bound. Then best to be discussing something we understand coming up with assumptions and how much friction to stick to the system. We might want to examine that in future work.

Mr. **Jewett**. Do you have any comments?

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[1] Jon J. Jewett, Associate Counsel, Committee on Environment and Public Works.

Mr. **Speyer**. I would add that to the extent you can get data on a State-by-State basis, or on a system-by-system basis, you can include that as a constraint, in terms of you can limit the amount that the model will go to low-sulfur coal versus scrubbing, and you can assume the two extremes or one completely efficient interstate trading and the other would be if you did the analysis on a system-by-system basis which is really too time-consuming to do. You would have to do it by a smaller system-by-system model which assumes only the system does it.

Mr. **Freeman**. Jon, I think in the ASEM analysis which we will be reviewing tomorrow you do have those kinds of friction costs added because each system had to bear in mind capital constraints and it also had to bear in mind political realities that may force it to do a less economic choice, particularly with local coal and long-term coal supply relationships.

Mr. **Beck**. I think what you have, though, is clearly both bounds. You have some of these studies that look at what happens if there is no interstate trading, and then you have got one which says what if you have that constraint removed. I guess you have a couple. So you know what the bounds are. I think the point is interstate trading is permitted then the costs will surely be lower than the costs if there is no interstate trading permitted and whether all of those savings will be realized or not, of course, depends on things that no one can know very well at this point.

Mr. **Speyer**. One thing to point out when you assume interstate trading, you are still assuming completely efficient intrastate trading and you really have to ask the people tomorrow whether they think that will occur in terms of whether northern Illinois will trade with southern Illinois. So I think the actual bound is probably something higher than no interstate trading, but there is a bound between the completely efficient interstate trading and something above what we have assumed is no interstate trading.

Mr. **Farrand**. I would like to add a postscript; that is, if you assume a maximum interstate trading, you will lower the cost, but you will also increase the employment impact if you believe the response will be coal switching. You maximize coal switching vis-a-vis a technology response.

Mr. **Freeman**. If you had $20 or $24 a barrel oil, you have one of two effects. Either that would depress coal prices across the board to meet the competition from the oil, or you would have oil generation displacing existing coal.

Mr. **Jewett**. On the subject of interstate trading, first to the Wildlife Federation, have you got a clear idea of the mechanics of how it would work?

Would it be State-to-State, or would it be conducted completely by the utilities; and second, what would be the result of it in terms of which States would make much greater reductions than they would otherwise make and which would make fewer reductions and pay the other States?

Mr. **Hawkins**. Answering the second question first, the emissions bought and sold are all displayed in section 3 of the report done for us. It indicates the transfers from State to State. So any particular one that you want I can give that to you. Is there any particular one?

Mr. **Jewett**. I was just wondering if there is any general trend? Does the Midwest make much greater reductions? The Southeast?

Mr. **Hawkins**. Middle Atlantic sells 12—these are all in thousands of tons, 12,000 tons, South Atlantic buys 184,000 tons, the East North Central, which is Ohio, Michigan, Indiana, et cetera, sells 36,000 tons; the South Central, which is the Tennessee Valley sells 56,000 tons; the west bank of the Mississippi, Missouri, and bordering States there, sells 86,000 tons.

That is 1990 with the Mitchell-type allocation. So yes, you see what you would expect which is that the areas that have large uncontrolled plants sell emissions because it is cheaper, reducing the plant, controlling the plant that has never been controlled before is cheaper than controlling one that is already being controlled.

As to the mechanics we would assume the institutional relationships would be very similar, if not identical to the existing institutional relationships for operation of generating stations that are currently operated by multicompany, multistate consortia.

We are talking about operating a piece of the generating station. They are already operating entire generating stations.

Mr. **Jewett**. I am just wondering about enforcement. I assume it would be the State's responsibility to make sure that they achieve their total?

Mr. **Hawkins**. The enforcement would be the same as it is for any of the other emission trading concepts that the current administration is practicing.

Mr. **Jewett**. They don't have interstate, through.

Mr. **Hawkins**. The jurisdictional issue does not complicate the enforcement issue. What complicates it is not from a Federal perspective; from the State perspective, the State that has jurisdiction over source A has to receive documentation from source A that it has a contractual or other relationship with some other source that discharges its obligation.

If it doesn't, then State A proceeds against source A.

Mr. **Freeman**. Jon, your question points up another thing we haven't brought up. It relates to what Dave just said. We have a real anomaly here in that the present Mitchell bill is based on actual emissions in 1980 versus allowable emissions.

That makes a big difference down here in the lower South because the utilities in these areas are burning much cleaner coal than they need to burn to meet the SIP's. That is because they are burning local coal. By basing it on actual versus allowable, you have displaced those local coals and they are already doing more than they are supposed to do in terms of meeting SIP's.

Mr. **Hawkins**. Which systems are you referring to?

Mr. **Freeman**. The Southern and that will be brought out tomorrow by the Southern Co. people.

Mr. **Hawkins**. One other point, just on the question of the sensitivity of the cost estimates to this interstate trading issue. I think table 2 of the ICF analysis that was done for EEI and distributed today is quite instructive on that point. It shows—that is on page 9. It shows that having no interstate trading costs you and additional billion dollars if you have a 12-million-ton-reduction program and it cost you an additional $400 million if you have an 8-million-ton-reduction program.

So that if you have a 12-million-ton-reduction program you have a boundary swing effect of $1 billion according to this analysis, if you have something less than a 12-million ton such as an 8-million-ton program you have a sensitivity of $400 million in your analyzed costs if you eliminate the interstate trading.

Mr. **Wagner**. We are muddying the waters slightly.

Our analysis shows a $200 million difference right now with and without trading. I didn't really want to get into that today until we have had a chance to examine it more carefully.

We will cover it. But it does appear that we should be cautious in jumping to how much you save by going to interstate trading.

Mr. **Beck**. I think you have to think about this whole problem clearly as you focus on it. The notion of having interstate trading is there in part in response to the kind of line of argument that has developed in the last few years to have more efficient pollution control regulations.

This is a division to increase efficiency. At the maximum, it saves a great deal of money. It has the other effect of increasing the swapping around the jobs in the coal markets. That is the other side of it.

The Congress can make a policy choice not to go to the maximum in efficiency if it wishes to minimize the impact on the coal markets and on coal mining jobs or it can go the other way. It is a straight-forward policy choice and I think it should be confronted honestly for what it is.

Mr. **Moore**. George, could I return to something you just said? I am trying to find it here. My recollection was that some of the Southern States you just mentioned were pretty far out of compliance with the SIP requirements. Am I recalling something incorrectly? I thought I saw it in your stuff, Bob. Alabama specifically sticks in my mind for some reason.

Mr. **Trumble**. Part of the problems with the SIP compliance calculations is truly the difficulty of finding out what the SIP compliance is State by State.

We have tried that a couple of times. We have made a few errors in stuff we have presented earlier. Some of the States call us. From the Washington level it is virtually impossible to find out what is going on.

I think maybe the EPA regional offices might be able to get in touch with the States or somebody get in touch with the States directly.

Mr. **Freeman**. We can certainly ask the Southern Company spokesman tomorrow the status of their compliance.

Mr. **Moore**. Maybe EPA could collect that data for us, what SIP compliance emissions are and what actual emissions are, actual current emissions are. Would that be possible?

Mr. **Stolpman**. Yes. In the interim there is an ICF report from, I think, 1980, that is a pretty good cut out of the ratio of the actual to the allowable based on what we can do about SIP's then.

Judging from the size of that report, you are asking us for a massive job that cannot be turned around in a week. I have tried it. It takes my staff, which is not as big as it used to be, a substantial amount of time. So I do not know how fast we can turn that around. We will take a look at what we have got.

Mr. **Moore**. If you would do that, I think it would be helpful.

Mr. **Stolpman**. I think an interesting thing to point out just how complex this regulatory process is, George was talking about the impact of the system that is well under an SIP, that unfortunately or fortunately cuts the other way.

If you are well under your SIP according to the allocation scheme of excess emissions, you therefore do not have the large excess emissions and you also therefore can't get hit as hard by the bill. So it cuts two ways. It is that complexity that I think we would like to make you aware of, is the little things that are contained in all of the bills that are out there, that have substantial cuts on where you come out and which States get hit harder or less hard.

Looking very carefully at those little things, we feel it very important in that as you continue to look at variance on the bills, we would suggest looking and maybe talking to all of the parties that now have experience in understanding what those different cuts do because the allocation scheme of using excess emissions can cut different ways.

Mr. **Moore**. Does somebody else have questions?

Lee Fuller.[2]

Mr. **Fuller**. Obviously most all of these tend to deal with annualized costs, some type of average annualized cost. One question is when do you assume that those costs begin and then how long do they exist once they are in place?

Mr. **Frankel**. The forecast, for instance, for 1990 that reflect annualized costs for 1990 are costs that are indicating costs beginning in 1990 that are annualized over the life of the powerplants. So it is depending on the life of the powerplants, somewhere near 30 years, somewhere 15 or 20, depending on the equipment. But it is basically annualized over the life of the equipment. So you have a present value notion over the life that is beginning in 1990 going out over the life of that.

Mr. **Fuller**. When I see a table that says annual costs, it is the cost at that particular point in time?

Mr. **Frankel**. That is right.

Mr. **Fuller**. If it is 1990, it is in 1990, if it is 2000 it is 2000.

Mr. **Fuller**. That is correct.

Mr. **Frankel**. In annualizing these bills, when did you assume the costs, the bills would result in the costs beginning to occur?

Mr. **Fuller**. The cost of cumulative over the period, for instance, if you are looking at the 1990 period of time, it is all the capital costs incurred between now and 1990. They are annualized as if they are beginning to occur in 1990. So it does not take into account, for instance, the spreading of capital costs between today and 1990 and a pro ration of those. In many respects a lot of those costs are going to be incurred at the end of that time where the bulk of the construction costs would be incurred.

It is possible to go back and try to spread those to indicate a specific construction schedule if you prefer to do that. That ends up affecting the cost, I think, a very minor amount compared to some of the other uncertainties.

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[2] Lee Fuller, Professional Staff Member, Committee on Environment and Public Works.

Mr. **Farrand**. Your question skirts around the two issues which the models don't really address. One is with respect to the costs incurred if the option is coal switching, the costs begin quite soon; one, because the operators of the utilities will know that they will have to scramble to lock up available supplies of low-sulfur coal.

You also cut our leadtime to get the mines in. They will probably go out immediately after passage of the bill and try to reserve the nearest available or let me put it another way, the best available coal supplies with the most reasonable transportation system connected thereto.

So if it is a case of an existing mine, they will start shipments on that coal right away in order to confirm that contract. That will be an operational response.

The other question, the other issue that your question gets at is the effect of the timing of this requirement.

If the timing is a firm 1990 and you have to and you believe that your best cost response is to retrofit a scrubber, the question then becomes what effect will the retrofit have on the useful life of that plant versus another option of waiting until a new plant is built on which a scrubber is already required?

If you do not have a new plant coming on line designed, sited, ready to go, there is no way that you can bring that new facility on to displace the existing sources between now and 1990.

So you are going to shift the economics of retirements and replacements a great deal by the date at which this requirement is imposed. That in turn will affect costs. It also affects obviously operational efficiency and long-term requirements, long-term imposition of larger controls because we don't build the plant just to replace the existing one. You build it to both back out a reitred source and meet new requirements. So it has a dual effect.

Mr. **Fuller**. I would assume then also that and the mine workers analysis on employment or effects on coal markets and employment effects would also be then the nearer term of the decade, in the first 5 years, as opposed to the last 5?

Mr. **Farrand**. We analyze them in terms of 1990. What I am saying is that they will begin sooner than that as people start to lock up their supplies of "acceptable" coal.

Mr. **Freeman**. One thing on that point, if the initial reduction required to take place in 1995 rather than 1990, the probability of having some more, better and less costly technologies of where you are having to go to the technological root would be much greater.

Mr. **Farrand**. That is true. I would like to emphasize that. No. 1, you have more time to build the plant from the ground up and it gets around the inherent problem of retrofitting scrubbers. So you end up over a much larger degree of response.

The resistance to the retrofitting are both technological and economic.

First of all, it is difficult to get capital and it is difficult to get capital to retrofit a plant that has no increase in output. So you have a difficult time allocating those costs, analyzing those capital costs. So the preference, I think, of our customers, would be to allow time for them to respond to these kinds of requirements by changing their entire system with the constraints of the capital market rather than retrofitting or amending the present system.

Mr. **Wagner**. I might add that at least in 1985 our figures would have expenditure of about annualized costs of about $200 million per year which is what has gone to $3.8 billion in 1990. By 1985, it is about $500 million in capital expenditures and by 1990, there is about $13.1 billion in capital expenditures. You shouldn't take these years as being this is going to happen exactly in 1990, 1990 is an example year.

Maybe it is 1989. Maybe it is 1991. It gives you a picture of sort of the curve of the cost build up over time.

Mr. **Speyer**. One thing I would like to add, is, I think this is a prelude to tomorrow. I think a lot of the utility systems look at it in terms of the first-year rate impacts which, as I indicated, if you assumed that most of the expenditures are made in the late 1980's, the first year impact would be approximately twice the average impacts but the rate of impacts in the later years would be less.

Mr. **Fuller**. Is that a reflection of the way that the utility commissions allow those costs to be moved into the rate base?

Mr. **Speyer**. Right. You move the whole thing into the rate base. You start depreciating it. So in the first years you will have a much higher rate impact. We do have a levelized cost. So in the sense we get the present value of the revenue requirements, the utilities give you a higher rate at the beginning, lower at the end.

Mr. **Freeman**. If you will mandate to the States that put the construction work in progress at the rate base——

Mr. **Beck**. No commercials.

Mr. **Moore**. Take advantage of any opening. Right?

Mr. **Freeman**. Right.

Mr. **Frankel**. I just saw yesterday that Pennsylvania does in fact pull out pollution controls equipment, although not generation equipment.

Mr. **Trumble**. We will support that.

Mr. **Fuller**. I guess this is something that cannot be easily answered at this point. But as I look at table 2 and the EEI handout, figure 1 of the OTA handout, I am struck by this dilemma.

The first is that there is obviously a difference in the cost of the annualized costs between the analysis 1 and analysis 4 in the EEI handout of $6.9 billion for analysis 1 and $2.6 billion for analysis 4.

First, I would like to understand what the elements are that cause that change. I am sure part of it is the difference in tons but I would like to understand what that difference in tons repesents in terms of those types of changes in the equipment or whatever that causes that change in cost.

Mr. **Speyer**. That is really a very complex question to answer. We can take a look. Obviously you are going to more scrubbing, more low-sulfur coal. The difference in the tonnage, you would have to go back to this table 1 where you see that OTA—well, EEI's interpretation of the Mitchell bill says that is a 10-million ton absolute ceiling, OTA's, 10 million with existing with credit from SIP compliance.

I think at this point, when you get up to 8-million tons and you should have it beyond 8 million or something like that, you are doing more, putting more scrubbers on, more switching of low-sulfur coal.

If you want additional detail, we can supply it.

Mr. **Farrand**. I would like to get an answer to that.

Mr. **Bartis**. The difference between the 13 million ton EEI figures and our own results, I think our results are comparable with the national or lower one of $2.7 billion.

Mr. **Fuller**. At the 8.0 million?

Mr. **Bartis**. The 10-million ton reduction, I am talking about the National Wildlife Federation.

Mr. **Fuller**. Option 3.

Mr. **Bartis**. Which is similar.

One of the things that we found is that once we start going beyond 10-million tons, what we have done is we have brought out the higher-sulfur coals. We are starting to put controls on coals of lesser than 2-percent content. So now we are getting fairly marginal benefits. So that the additional control costs are now about $600 to $800 per ton of SO_2 removed, whereas we take an entire range we have heard to control costs are 300 of the first 10-million tons and between $300 and $500 per million or per ton removal.

So we are really getting into an area where we are hitting the lower-sulfur coals. We are getting much less benefit out of it.

Mr. **Fuller**. I would like anybody who chooses to respond to that in more detail, if you would, but that is one of the things I am interested in.

Mr. **Speyer**. I think we can show you the marginal costs of scrubbing high- and low-sulfur coal, very insignificant increase. That is part of the reason as you move up these level reductions you get these big increases.

Mr. **Fulller**. Is there a well-defined break point in there where that change takes place?

Mr. **Bartis**. It is gradual. It keeps on going.

Mr. **Wagner**. You might also keep in mind you are seeing some other effects going on, depending on how you are setting that loading constraint in the first place.

For instance, you can be pushing people in New England from low-sulfur residue to distillate.

There are two things going on. Dominance probably is the budget constraint itself but how you design it could also be significant, certainly in the regions.

Mr. **Bartis**. I think one of the most important caveats to talk about, when you are talking about the reductions, is the fact the model, calculations, is sort of entering into an area where we cannot predict what is going to be happening.

We are talking about a fairly large disruption of the coal market. Most of the studies here, model studies, are talking about switching at least 50 percent of the coals to achieve their results and up to 75 percent, that includes not only the regional, but also the intraregional transfers.

So we are talking about switching between 100, 200, something around million tons of reduction from high-sulfur to low-sulfur coals.

Around 20 to 25 percent of total national coal production at present. When that happens, we have absolutely no idea what is going to happen to the coal market. We could give estimates of equilibrium but that is not what is going to take place. Because the coal market doesn't reach equilibrium within 5 or 10 years. It takes a lot longer.

Mr. **Moore**. Will that change occur in any event when all of the present capital equipment is turned over and replaced by new percentage reduction equipment?

Mr. **Bartis**. It is going—no. That doesn't affect the coal market.

Mr. **Moore**. What if the percentage reduction requirement is removed? Will that change occur?

Mr. **Bartis**. I don't see the percentage reduction for it being removed in such a way as it is going to twist that much around.

Mr. **Moore**. What if it is?

Mr. **Bartis**. I don't know. I haven't done that kind of analysis.

Mr. **Beck**. Could you let us know the basis for that?

Mr. **Hawkins**. Trying to give our understanding of the question earlier, about the table 2, EEI summary, if you start with Mitchell No. 1. the 6 point without interstate trading, have the $6.9 billion annualized figure, going to No. 2 that is reduced to 5.4.

There are two factors there that I understand. One is that you allow No_x for SO_x trades and you also allow reductions from industrial SO_2 emitters to be credited toward the total. That saves you $1.5 billion.

Dropping down to "With interstate trading" under No. 2 still, you save an additional billion dollars by allowing interstate trading, and moving over to No. 3, if you do not have an emissions cap you have less of a reduction of total emissions, 2-million tons less, but you also save another $1.5 billion and then, finally, moving to No. 4, which is the difference there is due to crediting SIP compliance which again reduces your emissions by another, it narrows your reductions by another 1.5 to 2 million tons and you save $600 billion.

So, those, I think, are the key factors that are policy options, if you will, that give you those different cost figures.

Mr. **Fuller**. Is that your opinions?

Mr. **Speyer**. Yes.

Mr. **Freeman**. One way to sort of simplify it and this is what we will be talking about in the individual system analysis, I think the ICF will sort of agree with this; is that if you mandate, as you go forward with more mandating more and more tonnages, you reach certain limits.

It is clear from everybody's view that the simple replacement of coal is the cheapest way and normally that is what utilities will try to do, rather than retrofit scrubbers.

We think that that point is somewhere between 3 billion and 4 billion tons; million tons. At that point, depending on the oil scenario which nobody has really done except EPA comes pretty close to it with theirs, I figure your oil price is about $25, assuming oil will drop to $25 you would then have one of the things that maybe your model shows, oil to coal displacement would then be the next most economical.

What we may have to do is to see how much actual replacement capacity is out there and nobody—we haven't run that yet.

Mr. **Ferrand**. I think I can accentuate that point. I have forgotten which run it was. In one of the early ICF runs on the Mitchell bill, it had several alternatives, including, I think, a 2-million and

5-million-tons, 10-million and 13-million-ton reduction. The 2-million-ton reduction had about 60 percent of the effect on coal displacement as the 10-million-ton reduction. So that economic effect takes place no matter what, that dislocation effect I should say.

Mr. **Freeman**. Remember that when we are talking about coal, we tend to think of low-sulfur coal versus high-sulfur coal as if they were two complete separate things and you have coal under 1.2 pounds per million Btu and then four, five and six-pound coal, but that is really not true. It is a continuing up that whole scale. Based on experience in the utility industry, I think you would give very serious consideration to scrubbing your lower high-sulfur coals, that is coals between 1.2 and 3 pounds, rather than scrubbing your high-sulfur coal if you have the option because the number of scrubbers, the efficiency of the operation, maintenance costs and so forth are so much less and that is what we found out in the present round of percent removal.

So the last thing you put the scrubbers on is the high-sulfur coal.

Mr. **Moore**. Bob, I notice you tugging at your beard. Does that mean you have something to say?

Mr. **Trumble**. I just wanted to throw in a couple of points as far as comparisons of the ICF versus our estimates.

One thing I am not sure is clear. The ICF ranges on table 2 are with interstate trading and without interstate trading, it ranges that we have shown on our figure 1, our lower range is with interstate or with intrastate trading but no interstate trading and our upper range is that cap cost that the inefficiencies you were talking about, the effects of market, for instance, and so on, our numbers show about a 30-percent difference between allowing trading within the State and not allowing any trading within the State.

As far as at what range on this emissions reductions curve, switch to scrubbers or low-sulfur coal fuel switching, it is a continuum. The numbers are very dependent upon the relative prices of scrubbers and cleaner coals. So from scenario to scenario and the assumed prices, you really do find difference between percent use of scrubbers versus percent use of fuel switching. But you don't find that same sensitivity on control costs, on the total of the control costs, because much of the switching is because it is a few percent cheaper, 10 percent or whatever to use one technique or another in another plant.

We have seen several estimates. The Peabody estimate of all fuel switching comes fairly close to the estimates, cost estimates of the mix of scrubbers and fuel switching, as well as what might be used by the utilities. I guess a number of times the statement has been made that the utilities would prefer the fuel switching. I guess we will hear about that tomorrow. But just looking at the list Peabody has prepared, American Electric Power, as I remember their statement, was almost entirely scrubbers, Wisconsin Electric Power and Wisconsin Power & Light were all, their cost estimates were based on scrubbers and not fuel switching.

So I guess we will hear tomorrow which way the utilities might prefer.

Mr. **Freeman**. I think you will hear tomorrow that in many instances, those do represent friction costs and, politically, it becomes very difficult to give up all burning of Ohio coal in Ohio.

Mr. **Curtis**. I really do think as far as fuel switching is concerned that fuel switching and the most important economic one is increasing railroads. So while you have fuel switching, this coal, central and I think this is what the announcement showed, this central Appalachian coal is where most of the coal would be substituted here and parts of it here, I don't think you would get western coal any further than Illinois because of the uncertainties about rates now that the rates have been decontrolled and the experience in the utility industry has been a lot of times they feel gouged by the long-term western railways.

So if they were looking ahead, I think maybe Peabody would have realized that they would look first east, look mostly at that Appalachian, Central Appalachian area.

Mr. **Farrand**. There is another reason for that. We analyzed I think in our fact sheet here, we looked at 243 million tons of coal replaced. The number I gave you in the testimony is 307. The difference is we looked at the coal displaced in the 31-State region. The remainder is from outside of the 31-State region whose production cannot meet the limits they would have to meet in order to comply with the act.

We produced coal from the Outer River Basin, the Montana portion, for use in Minnesota. It would have to be backed out or at least blended to an extent if we counted the extent of blending. It cannot meet the limits. There is a myth about how accessable some of these low-sulfur coal supplies are. The reason is you pay a very heavy Btu penalty on that Western coal. There is one other point I would like to make that the models did not address.

That is the regulatory constraint against the retrofitting of scrubbers. If you switch coal supplies in most States you simply pass that additional delivered unit cost differential along as a fuel adjustment on the consumers bill. The retrofit of scrubbers, you have to go to the rate commission, you have to build a capital charge into your rate base which is not only time consuming and difficult but it is frankly something the utilities loath to do because they would rather wait and go in and get a brand new plant built. So the suggestion therefore is that they would go beyond the equal costs between scrubber and fuel switching and fuel switch above that cost simply because of the hassle factor connected with the commission.

Mr. **Freeman**. That is why 1990 versus 1995 becomes so important. Because rather than retrofit the old plant with the scrubber, it might be a lot cheaper to really build, to just build a substitute plant, a new one from the ground up.

Mr. **Fuller**. Let me touch on another second issue associated with the two different figures. This may be in part just the ability to read the figures. If I read your assessment, OTA assessment on sulfur reduction for 10 million tons, I assume that is over the 10-year period, I would get a number in 1979 dollars of something in the league of $4 billion which I would escalate to roughly $5 billion for 1982.

Mr. **Trumble**. In 1982 the range would be around 4 to 5, the 4 corresponding to trading within a State but not between States.

Mr. **Fuller**. I would then look at this ICF table which determines that cost some place in the league of $2½ billion to $3 billion I would assume. I would like to understand why there is that disparity because I would assume that disparity would also extend if you go to higher or lower amounts of total renewable.

Mr. **Trumble**. The figure that would be most appropriate for comparison would be around the 2.8. In fact, we charge out instead of 8.1 million tons, closer to 8½ million tons. So ir would be a little higher than that, maybe around $3 billion. Ours are first-year annualized costs, again the first year costs which we have talked about a little bit before. Our model assumes a lot of historical information, that is, history is the best guess of the future rather than trying to make projections on what future costs might be.

So if the utilities in a given State are using expensive coals now for whatever reasons, even though there are cheaper coals available, our model assumes that they will be using more expensive coals some time in the future. Predicting the future is very tricky business. So we just take current assumptions. I think you will see some of the differences there. But I think our estimates seemingly are about 25, 30 percent higher than the ICF estimates at the same emission reductions as well as ours climb a little bit faster at the greater than 10-million-ton reductions than the ICF estimates.

Mr. **Speyer**. We will send you a memo we have written on some of the reasons that we see differences between our model and the model they use. It is too complex to get into here. He will send you a memo. If you have any questions feel free to give me a call.

Mr. **Freeman**. One thing we will also be furnishing you fairly soon, we will have ICF run their model to determine the costs under the Danforth proposal. But Jim has calculated what the 3 mill tax would do. I have those figures. You might be interested in it. If the tax in 1982 dollars in 1990 would produce $2.9 million if you took, assumed the 31-State region.

Mr. **Moore**. M as in Mike or B as in boy? You said $2.9 million or billion?

Mr. **Freeman**. $2.9 billion and in the 22-State region, the 3 mill tax would produce $2.2 billion in 1982 dollars. There is no way to compare that 22-State region with the cost figures. That is one of the reasons we are doing the run. But for the full 31-State region, the shortfall—this would be the comparison between the $2.9 billion and Peabody, ICF and OTA number, the Peabody number is, I believe, $4 billion and so you would have a $1.1 billion shortfall and if you made it up, you would have to have a 5 mill tax. ICF's EEI number is $6.9 billion. So you would have the $4 billion shortfall which you would have to make up with an 8 mill tax and the OTA number is $5 billion I believe.

You would have to there have approximately a $2 billion shortfall and you would have to make up that up by increasing it to a 6 mill tax.

Mr. **Moore**. Jim Davenport has a question. Before he goes to it, one point I wanted to ask if you would submit for the record. Using Peabody and UMW calculations as to the States where a minor employee disruption would be the greatest, what would be the effect on employment and costs if the emissions reductions in those States had to be met by scrubbing as opposed to fuel switching? Or a technology as opposed to fuel switching?

Mr. **Farrand**. Using what point?

Mr. **Morre.** Using 10.

Mr. **Farrand.** No. I meant you said the highest States in terms of employment impact.

Mr. **Moore.** Let's say the eight.

Mr. **Farrand.** Top 10?

Mr. **Moore.** Let's say the top eight States. If you could just submit that, some of you might know that sort of anecdotally or intuitively but I don't think you would have it right now. Jim?

Mr. **Davenport.**[3] I wanted to follow up on Lee Fuller's question and inquire if it would be possible to have this information on figure 1, and the information on figure 2 of the ICF study, if we could have ICF put their information in this same form so that we could lay them side by side and see what we have.

Then also if we could have the OTA study run out to the Mitchell 1 and 2 which are the ICF proposals here so that we could see, on paper, how the two relate to each other. You are going to get into the differences in your assumptions. I would say go ahead and keep your assumptions distinct rather than trying to merge them toward each other so we can see, based on the assumptions, whether the relationships between the various proposals are maintained notwithstanding the differences in assumptions.

I think that would be very helpful.

Mr. **Wagner.** Could I suggest you might want to look at it in a slightly different way? We are seeing differnces and some of the differences are differences in assumptions, like oil prices, how many gigawatts capacity and those are going to have some effect on why estimates are different. But an awful lot of the differences are different interpretations of what is required. It might be another fruitful avenue to pursue, would be how those differences are changing the results. Why costs are different. The use of a capital increase costs in a different way than allowing trading. Examine it in that way rather than having graphs which show that you have a scatter. What is important is what causes the scatter more than its absolute levels.

These are almost design questions.

Mr. **Bartis.** What I am hearing here is it is almost a consensus of range. It is a very close range that everybody is at between $300–$500 per ton. I believe that is what we are hearing on an annual basis. I think the $4 million, I wonder how accurate that range is. Everybody uses common assumptions in getting that range. They talked about either projections of an equilibrium market in coal or they talked about the historical differences between different types of coal. So I think you can't get better in this kind of range. I think this range is pretty accurate.

It is about as exact as you can be.

Mr. **Davenport.** My only request, given that fact, is to put all the information in the same format so that it can be compared against each other.

Mr. **Trumble.** I think in the red DOE book that was handed out there are a lot on one of the tables, one of their graphs in there already put on that. There is actually a graph in there.

Mr. **Davenport.** It is already in that form?

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[3] James H. Davenport, assistant counsel, Committee on Environment and Public Works.

Mr. **Trumble**. Yes, and throwing on the ones that we have heard today on top of those might be a useful exercise. There are 20 different scenarios there.

Mr. **Bartis**. They go on and on.

Mr. **Moore**. Let me say that I plan to adjourn this session at 1 p.m. It looks to me like most people are getting tired. Linda, you had a question?

Ms. **Findlay**.[4] I had a question for Peabody and UMW. You mentioned these are jobs displaced, not a net number, taking gains and losses and balancing them out. I wonder if you could submit to us some more detailed information on the net numbers, taking into account the gains. I think you said in southern West Virginia, eastern Kentucky, and Virginia?

Mr. **Farrand**. Yes. The problem is you have estimates, very strong assumptions about where the replacement coal will come from. How that coal will be mined.

Ms. **Findlay**. But you are making assumptions that some of this is just lost, just evaporates when you do your multiplying? This money is moving around. Some of it is not going to go out of the region.

Mr. **Farrand**. I think we say in our statement that at least two States that some and perhaps all of the job losses in one area of the State will be made up for perhaps by a production in another part of the State, but we were not able to quantify that because we can't crawl into the inside of the heads of the fuel buyers to determine where they are going to buy that fuel. We have a number of options. We know where they are not going to buy it. We know where they but it now and they can't use it. Where they will purchase that is something they will have to determine. We just don't have the capability of making that judgment.

Ms. **Findlay**. You are contributing something like $1 billion in total annual economic losses to the State of West Virginia and in fact high sulfur-low sulfur is going to switch.

Mr. **Farrand**. If in fact they buy the coal in West Virginia. If they decide to go to Kentuky or Virginia——

Ms. **Findlay**. Can you give us your best guess?

Mr. **Farrand**. We do this—we don't have runs.

Ms. **Findlay**. I think it discredits this. You might want to be a little more straightforward in terms of ——

Mr. **Farrand**. I take exception to that. You said flatly that these were displacements. We will tell you from our own standpoint that if you move a mine, if you close a mine, open up a mine in another part of the State, those people do not move. They flat out do not move. They stay there.

Ms. **Findlay**. Wouldn't somebody else though. Let's say those particular people don't move, will not someone else be employed there? Won't the multiplier effect——

Mr. **Farrand**. Somebody will and how many, depends on where they buy the coal, what kind of money they engage in.

Mr. **Moore**. Could I suggest that what you do, if it is at all possible, in order to obtain this information is use the assumptions in terms of coal productivity which are contained in the OTA report and try to translate that using your figures on miner productivity per ton in terms of job creation and job losses by area?

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[4] Linda Findlay, professional staff member, Committee on Environment and Public Works.

Mr. **Farrand**. The problem is I can't determine what area they are going to buy the new coal from.

Ms. **Findlay**. I am saying OTA has made certain assumptions.

Mr. **Farrand**. If we can aggregate the three areas of the East, we could come up with where there is low sulfur coal.

Ms. **Findlay**. Assume OTA and the Congressional Budget Office are correct in their calculations of where the coal will be bought because they have made certain assumptions. Recognizing all of the caveats which you will of necessity attach to those calculations, nonetheless just assume for the sake of argument that they are right and see what the job increase might be because of dislocation.

Mr. **Freeman**. We have not done that kind of a study but we have a pretty good feel of where we think the coal will go, what general areas it will move from because of the railroads. The railroads, the transportation rates and so forth are important. We think your displacement in Missouri consumption and Illinois consumption and in this tier State will come from the Western coals. In here, we think that in region 4 we think the coal will be southern Appalachia, central Appalachian coal, in this whole are, 4 and 3, and to the extent coal is used here in New England, it will clearly come down the C. & O. and go up by water there. The Kentucky coal will largely move into Ohio and Indiana to displace those local coals.

Mr. **Moore**. Just see if you can get us a figure, qualify it all you want to.

Mr. **Bartis**. The DOE analysis looked at the displacement problem at hand. It is very sensitive to two factors. One is how much new coal is surface mined versus undergound mined. All the other problems are how much additional coal production doesn't take place because low-sulfur coals go up. These are choice coals for the industrial boilers and they are the export coals. Right now the export market which is a growing market is quite marginal for the United States. It is a long story why. But it is a very marginal market. If that goes up another $10, $15, we won't have an export market. But again for industrial users, there is a marginal price difference because they are at a smaller boiler, a marginal price difference between coal, oil, or gas, that is what will affect the future coal production. There will be a new loss of jobs because the cost will go up.

Mr. **Frankel**. Is there anything wrong with taking in your table 2, taking total tonnage and total costs and getting an average cost per ton?

Mr. **Speyer**. That is the average. You should also look at the marginal.

Mr. **Frankel**. I have heard occasionally, the first year annualized costs used, is that different from an annualized cost?

Mr. **Speyer**. Yes. It is different approximately a factor of two if you assume that most of the expenditures would be made in the late 1980's. If you are here tomorrow, I think part of the reason why the utility impacts are greater is they are talking about first-year rate impacts, we are talking more about average rate impacts.

Mr. **Frankel**. The first year annualized costs will be larger.

Mr. **Speyer**. We wouldn't calculate it that way. We would calculate first year revenue requirements. We can come up with that estimate. It would be just revenue requirements that you would need to cover from the public utility perspective and that will just be the first year costs. It wouldn't be first year annualized costs.

Mr. **Trumble**. Our difference in first year annualized costs is not that difference between our annualized costs that we calculate. We use the term first year annualized to mean that we don't assume any real price increases in either operating costs or fuel prices or whatever. That is left out of the calculation just to be able to compare to what we pay for things today.

Mr. **Speyer**. There is really no analysis that has been done by the people that presented today, has looked at first year rate impacts. It can be done. We can modify our model to do it. I think the utility analysis tomorrow will look at first year rate impacts.

Mr. **Moore**. Any other questions? I have one further request and that is if the various groups would, if they are able to, submit for the record what would be the least cost in terms of money, No. 1, and what would be the least cost in terms of jobs, methods of achieving a 10-million ton reduction.

Mr. **Wagner**. Ten million tons capping new growth? If you will define 10 million tons?

Mr. **Bartis**. Is waiting 15 years an appropriate answer?

Mr. **Moore**. Waiting 15 years?

Mr. **Barr**. What about a stretchout?

Mr. **Freeman**. Ninety-five rather than ninety.

Mr. **Barr**. Seriously, are you limiting the assumptions?

Mr. **Moore**. I will put it in writing and send it to you.

All finished? See you tomorrow morning at 10 o'clock for those who are interested.

[Whereupon, at 1 p.m. the briefing on acid rain recessed, to reconvene at 10 a.m., Thursday, June 3, 1982.]

[Statements and responses to written questions follow:]

SUMMARY OF ACID RAIN ANALYSES UNDERTAKEN BY ICF FOR THE EDISON ELECTRIC INSTITUTE, NATIONAL WILDLIFE FEDERATION AND ENVIRONMENTAL PROTECTION AGENCY

Prepared by

ICF, Incorporated

for

Edison Electric Institute

May, 1982

SUMMARY OF ACID RAIN ANALYSES UNDERTAKEN BY ICF FOR THE EDISON ELECTRIC INSTITUTE, NATIONAL WILDLIFE FEDERATION AND ENVIRONMENTAL PROTECTION AGENCY

INTRODUCTION

ICF has undertaken several studies over the past year analyzing the impacts of alternative acid rain mitigation strategies on the electric utility and coal industries. This report summarizes the findings of the acid rain studies which ICF has done for EEI, EPA and the National Wildlife Federation (NWF). This report is divided into four sections. The first section describes the different acid rain analyses included in this report. The second section summarizes the cost and coal production impacts of these analyses. The third section discusses the principal factors that account for the differences in the forecasted impacts of the alternative acid rain analyses. The final section discusses caveats and key uncertainties.

DESCRIPTION OF MAJOR ACID RAIN ANALYSIS

ICF has conducted numerous acid rain analyses over the past year, including proposals requiring emission reductions ranging from 1.7 to 13.1 million tons from forecasted utility sulfur dioxide emissons in 1990. We do not intend to include the findings of all these different proposals in this report. Instead, we have selected eight alternative proposals, which cover the complete range of proposed emission reductions in order to demonstrate how the cost and coal production impacts change as one moves from lower to higher levels of required emission reductions. The proposals included in this report are summarized in Figure 1 and are briefly discussed below.

1. January, 1982 EEI Analysis of Mitchell Bill -- In January, 1982, EEI had ICF rerun its December, 1981 analysis of the Mitchell Bill with two modifications (see Alternative 2 on page 4): (1) no cost effective emission reduction in utility nitrogen oxide and industrial sulfur dioxide and (2) no interstate trading. As shown in Table 1, these modifications resulted in a 13.1 million ton reduction in forecasted emissions in 1990.

FIGURE 1

SUMMARY OF ACID RAIN PROPOSALS

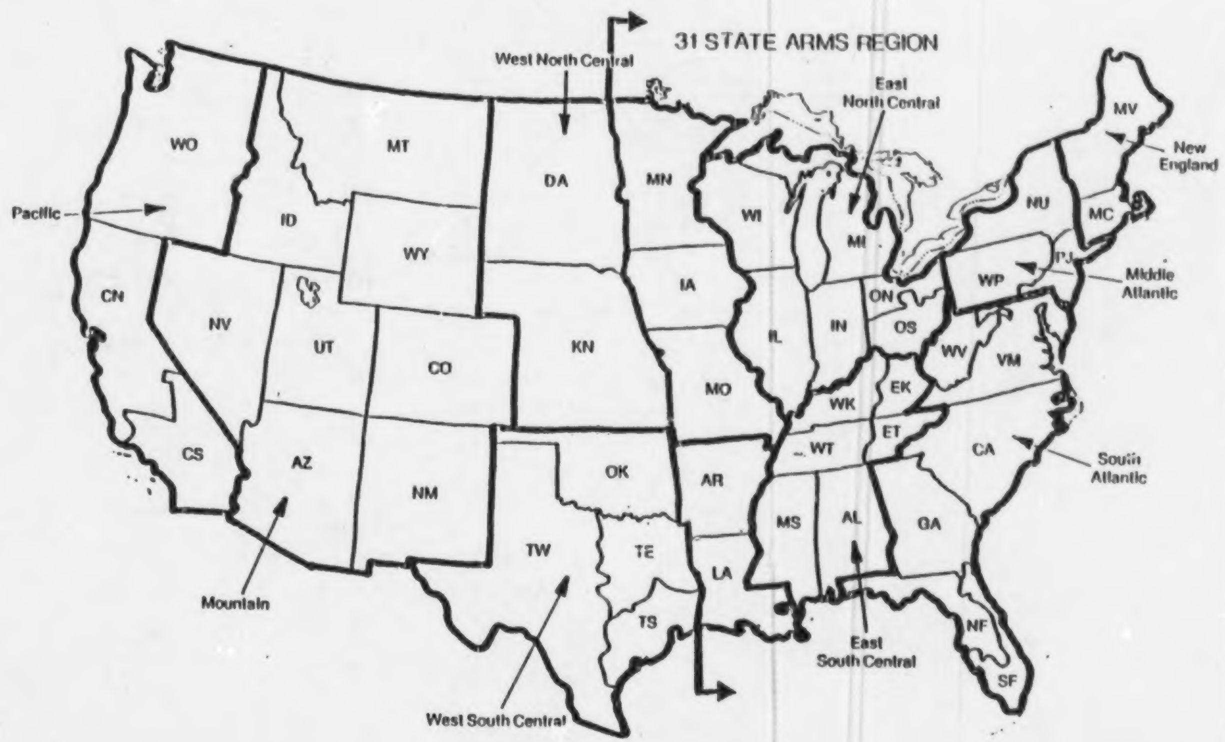
Alternative Cases	Description	Required Reductions in Forecasted 1990 Utility Sulfur Dioxide Emissions in the ARMS Region (Million Tons) [1] [2]
Mitchell Bill Analyses		
1	January, 1982 EEI Analysis of Mitchell Bill	13.1
2	December, 1981 EEI Analysis of the Mitchell Bill	12.0
3	NWF Interpretation of the Mitchtell Bill	10.0
4	OTA Interpretation of the Mitchell Bill	8.1
Other Analyses		
5	Thirty percent rollback in the ARMS Region	5.1
6	Two million ton reduction in total emissions in the ARMS Region	4.0
7	4.0 Pound cap on sulfur dioxide emissions	2.7
8	Ten percent rollback in the ARMS Region	1.7

1/ Using assumptions specified by EPA, ICF calculated utility emissions in 1990 under current environmental regulations to be 17.1 million tons. Using assumptions specified by EEI, ICF forecasted utility emissions in 1990 under current environmental regulations to be 18.3 million tons. This range of estimates is due to different assumptions concerning electricity growth rates, installed nuclear capacity, scrubber costs, price and availability of gas, etc. See Appendix B for a comparison of the assumptions used in the EPA and EEI analyses.

2/ See Figure 2 for a map of the ARMS region.

FIGURE 2

CEUM DEMAND REGIONS


31 STATE ARMS REGION
West North Central
East North Central
New England
Middle Atlantic
South Atlantic
East South Central
West South Central
Mountain
Pacific
WO
MT
ID
DA
MN
WI
MI
MV
NU
MC
CN
NV
WY
UT
CO
KN
IA
IL
IN
ON
OS
WP
PJ
WV
VM
MO
WK
EK
CS
AZ
NM
OK
AR
WT
ET
CA
TW
TE
TS
LA
MS
AL
GA
NF
SF

2. December, 1981 EEI Analysis of Mitchell Bill -- In December, 1981, EEI had ICF analyze the Mitchell Bill using the following major assumptions:

    -- Ten million ton reduction (allocated according to the rules in the Mitchell Bill) in total sulfur dioxide emissions from 1980 levels in the ARMS region.

    -- Total nitrogen oxide emissions could not exceed 1980 levels.

    -- Additional reduction was required in utility sulfur dioxide emissions to offset growth (between 1980 and 1990) in utility and industrial emissions of sulfur dioxide and nitrogen oxide.

    -- There would be cost-effective reductions of utility nitrogen oxide emissions and industrial sulfur dioxide emissions.

    -- The trading ratio between nitrogen oxide and sulfur dioxide reduction was two for one.

    As shown in Table 1, the net effect of the above assumptions was a 12 million ton reduction in forecasted utility emissions in 1990. This alternative was analyzed both with and without interstate trading.

3. Ten Million Ton Rollback in Emissions in the ARMS Region in 1990 -- This alternative was done for NWF using the following major assumptions:

    -- Ten million ton rollback in forecasted utility sulfur dioxide emissions in the ARMS Region by 1990.

    -- Completely efficient interstate trading was assumed.

    As shown in Table 1, the net result was a 10 million ton reduction in forecasted emissions in 1990.

TABLE 1

SUMMARY OF SELECTED ACID RAIN
ALTERNATIVES ANALYZED BY ICF

	Analyses of Mitchell Bill				Other Analyses			
	EEI (Jan.) #1	EEI (Dec.) #2	NWF #3	OTA #4	EPA/ Acid Rain #5	EEI/ Rollback #6	EPA/ Acid Rain #7	EPA/ Acid Rain #8
	10 mmton from total 1980 emissions	10 mmton from total 1980 emissions	10 mmton from forecasted utility emissions	10 mmton from existing utility emissions	30% Rollback from forecasted utility emissions	2 mmton from total 1980 emissions	4.0 lb. Cap on sulur dioxide emissions	10% Rollback from forecated utility emissions
Additional Required Reductions								
-- Offset Growth in								
-- Utility Emissions								
-- SO_2	1.5	1.5	x	x	x	1.5	x	x
-- NO_x	0.7	0.7	x	x	x	0.7	x	x
-- Industrial Emissions								
-- SO_2	0.7	0.7	x	x	x	0.7	x	x
-- NO_x	0.2	0.2	x	x	x	0.2	x	x
-- Prevent Exceedance of 1980 Levels in Any State	x	x	x	0.6	x	x	x	x
Total Additional	3.1	3.1	x	0.6	x	3.1	x	x
Credits for								
-- SIP Compliance	x	x	x	(1.4)	x	x	x	x
-- Cost-Effective Reductions								
-- Utility NO_x	x	(0.8)	x	(0.8)	x	(0.8)	x	x
-- Industrial SO_2	x	(0.3)	x	(0.3)	x	(0.3)	x	x
Total Credits	x	(1.1)	x	(2.5)	x	(1.1)	x	x
Net Required Reduction in 1990 in ARMS Region (million tons)	13.1	12.0	10.0	8.1	5.1	4.0	2.7	1.7

4. OTA Interpretation of Mitchell Bill (10 million ton reduction from existing sources) -- This analysis was done for EEI in December and corresponds to what we believe is OTA's interpretation of the Mitchell Bill. The major assumptions were:

    - Ten million ton reduction in sulfur dioxide emissions from existing utility sources (allocated to each state according to the rules specified in the Mitchell Bill).

    - No additional reductions were required to offset growth in emissions from new sources except that total emissions in any state could not exceed total emissions in 1980.

    - There would be cost-effective reductions in utility nitrogen oxide emissions and in industrial sulfur dioxide emissions.

    - The trading ratio between sulfur dioxide and nitrogen oxide reductions was two for one.

    As shown in Table 1 on page 5, the net effect of the above assumptions was a 8.1 million ton reduction in forecasted sulfur dioxide emissions in 1990. This alternative was analyzed both with and without interstate trading.

5. Thirty Percent Rollback in the ARMS Region -- This analysis was done for EPA and required that total utility sulfur dioxide emissions in the ARMS Region be reduced by 30 percent from forecasted 1990 emissions. This resulted in a requirement to reduce sulfur dioxide emissions in 1990 by 5.1 million tons. The states were free to trade among themselves to achieve this emission reduction (i.e., completely efficient interstate trading). ICF also analyzed the impact of requiring a 30 percent rollback in each of our demand regions which is roughly equivalent to assuming no interstate trading (i.e., uniform rollback in each state).

    As shown in Table 1, the net result of the above assumptions was a 5.1 million ton reduction in forecasted utility emissions in 1990.

6. Two Million Ton Reduction in Total Sulfur Dioxide and Nitrogen Oxide Emissions in 1980 from Stationary Sources in the ARMS Region -- This analysis was done for EEI and used the following major assumptions:

   -- Two million ton reduction (allocated according to the rules in the Mitchell bill) in total sulfur dioxide emissions from 1980 levels in the ARMS region.

   -- Total nitrogen oxide emissions from stationary sources could not exceed 1980 levels.

   -- Additional reduction was required in utility sulfur dioxide emissions to offset growth (between 1980 and 1990) in utility and industrial emissions of sulfur dioxide and nitrogen oxide.

   -- There would be cost-effective reductions of utility nitrogen oxide emissions and industrial sulfur dioxide emissions.

   -- The trading ratio between nitrogen oxide and sulfur dioxide reductions was two for one.

   As shown in Table 1, the net result of the above assumptions was a 4.0 million ton reduction in forecasted utility sulfur dioxide emissions in 1990. This alternative was analyzed both with and without interstate trading.

7. 4.0 Pound Emission Cap -- This analysis was done for EPA and limited emissions from each plant to no more than 4.0 pounds sulfur dioxide per million Btu. This resulted in a 2.7 million ton reduction in forecasted sulfur dioxide emissions in 1990. No interstate trading was allowed.

8. Ten Percent Rollback in the ARMS Region -- This analysis was done for EPA and required that total utility sulfur dioxide emissions in the ARMS Region be reduced by 10 percent from forecasted 1990 emissions. This resulted in a required sulfur dioxide emission reduction in 1990 of about 1.7 million tons. The states were free to trade among themselves to achieve their emission reduction liabilities (i.e., completely efficient interstate trading was assumed). ICF also analyzed the impacts of requiring a 10 percent rollback in each of our demand regions which is roughly equivalent to assuming no interstate trading (i.e., uniform rollback in each state).

SUMMARY OF FINDINGS

This section summarizes the cost, emission, and coal production impacts of the acid rain alternatives discussed above. A later section discusses the major reasons for the differences in impacts between the various alternatives.

Costs and Emission Impacts

The national cost and emission impacts of the acid rain alternatives are summarized in Table 2. The principal findings are:

- The annual cost starts increasing rapidly for emission reductions of greater than 5 million tons. This is because the marginal costs of emission reductions increase with increasing reduction requirements (See Table 2). This means that the cost of emission reduction per ton of sulfur dioxide removed progressively increases as higher levels of reductions are required.

- In view of the increasing marginal costs with higher reduction requirements, the marginal cost should be compared to the marginal benefits in evaluating the alternative regulatory proposals analyzed in these reports.

- The annual costs of alternative regulatory approaches would be less if interstate trading is feasible. For example, the December, 1981 EEI analysis of the Mitchell bill estimated that the cost savings associated with interstate trading in 1990 would be about 1 billion dollars. However, as discussed later, interstate trading may not be politically feasible.

- Except for uniform rollback alternatives (i.e., #5 and #8), the cost impacts are highly uneven across different states (see Appendix A for state-by-state details of cost impacts). Thus in alternative #1 through #4, which require an emission reduction greater than 8 million tons, over 70 percent of the total costs in 1990 are forecast to be incurred in the ten states listed below:

  -- Illinois
  -- Indiana
  -- Kentucky
  -- Michigan
  -- Missouri
  -- Ohio
  -- Pennsylvania
  -- Tennessee
  -- West Virginia
  -- Wisconsin

TABLE 2

SUMMARY OF THE COST AND EMISSION
IMPACT OF SELECTED ACID RAIN ALTERNATIVES
IN 1990 IN THE ARMS REGION

	Actual 1980	Forecasts under current environmental regulations	Changes Under Alternative Proposals[a/]							
			Analyses of Mitchell Bill				Other Analyses			
			#1	#2	#3	#4	#5	#6	#7	#8
• SO$_2$ emissions (Million tons)	16.2	18.3b/	(13.1)	(12.0)	(10.0)	(8.1)	(5.1)	(4.0)	(2.7)	(1.7)
• Annual Costs (Billion 1982$)										
- without interstate trading	-	-	6.9	5.4	c/	2.6	1.6	1.3	0.8	0.5
- with interstate trading	-	-	c/	4.3	2.8	2.2	1.1	0.7	c/	0.1
• Cumulative Capital Costs (Billion 1982 $)										
- without interstate trading	-	164.4	26.2	20.8	c/	7.6	9.5	2.9	1.6	1.5
- with interstate trading	-	164.4	c/	16.2	14.7	6.2	4.2	0.2	c/	1.0
• Marginal Cost Per Ton of SO$_2$ Removed (1982 $/ton)										
- without interstate trading	-	-	-	-	-	-	-	-	-	-
- with interstate trading	-	-	c/	865	971	458	d/	320	c/	d/
• Maximum Percent Change in Electricity Rates For any State[e/]										
- without interstate trading	-	-	23.3	17.6	c/	11.4	5.2	11.7	3.5	8.0
- with interstate trading	-	-	c/	11.8	8.2	5.8	4.0	3.3	c/	0.8

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a/ See page 2 for a description of the alternative proposals.

b/ Under EEI assumptions. Under assumptions specified by EPA, the forecasted 1990 utility emissions of sulfur dioxide were 17.1 million tons.

c/ No runs were made for these cases.

d/ Not reported.

e/ The state-by-state details are reported in Appendix A. It may be noted that the % change in the electricity rate is calculated from 1980 electricity rates for alternative #1 but from forecasted 1990 rates for all other alternatives. The forecasted 1990 rates, however, are different for the EPA/NWF and EEI alternatives due to differences in base case assumptions.

Correspondingly, for these alternatives, over 80 percent of the emission reductions in 1990 are forecast to occur in these states. The cost impacts of the remaining two alternatives (i.e., #6 and #7), which do not require uniform rollbacks, are also highly uneven. For example, under alternative #7, five states, (i.e., Indiana, Missouri, Ohio, Illinois and Wisconsin), account for over 60 percent of the total cost in the ARMS region.

- The distribution of cost and emission impacts on a state by state level depend upon a number of factors besides the level of required emission reduction: 1) allocation of initial liability (i.e., uniform rollback or excess emission rate approach as used in the Mitchell bill); 2) need to offset growth of emission at new and/or existing utility and non-utility sources; and 3) feasibility of interstate trading.

- The impacts of electricity rates vary considerably from state to state e.g., from less than a one percent increase to more than a 20 percent increase in some states under the January, 1982 EEI analysis of the Mitchell bill (see Appendix A for state-by-state impacts of electricity rates under alternative acid rain cases). The variation in electricity rate impacts (and the variation in the impacts on annualized costs), would be even greater for individual utility systems.

- The electricity rate impacts depend not only on the annualized cost impacts and total generation (and therefore on the annualized cost impact per unit of generation) but also on whether the impact on rates is calculated based on current or forecasted electricity rates. There are significant differences between current and forecasted electricity rates. All of the electricity rate impacts reported in Table 2 (and in Appendix A) with the exception of the forecasts for the latest analysis for EEI (i.e., alternative #1), were calculated as a percent of forecasted 1990 rates.

- The annualized cost and electricity rate impacts presented in this report are calculated on a levelized basis. These are not first year impacts. The first year rate impacts could be significantly different, due to the impact of many factors such as accelerated tax write offs, investment credits, etc.

Coal Production Impacts

The regional coal production impacts in 1990, of the alternatives considered, are summarized in Table 3. The principal findings are as follows:

- Switches to lower sulfur coal are generally more cost-effective than installation of scrubbers. Hence, substantial shifts to lower sulfur coals are forecasted. Production, therefore, is forecast to increase in low-sulfur producing regions (e.g., Central Appalachia and the West) and decrease in high-sulfur producing regions (e.g., Northern Appalachia and the Midwest).

- For required emission reductions of less than 4 million tons (from forecasted emissions in 1990), the regional coal production impacts are not that large, especially in Northern Appalachia.

- For required emission reductions greater than five million tons, coal production in Northern Appalachia and the Midwest is forecast to decline to levels lower than actual production in 1979.

- The only way to mitigate the coal production impacts of acid rain proposals, such as the Mitchell bill, would be to delay most of the required reductions to the post-1995 or 2000 period when the development of new generation technologies (i.e., fluidized-bed combustion, combined-cycle gasifiers, etc.) could make the use of high sulfur coal cost-effective.

SUMMARY OF PRINCIPAL FACTORS THAT RESULT IN THE DIFFERENCES IN THE IMPACTS OF ALTERNATIVE ACID RAIN PROPOSALS

There appears to be six major factors which account for most of the differences in the forecasted impacts of the alternative acid rain proposals included in this report. Each of these is briefly discussed below:

- The specified level of emission reductions -- This is the most important factor. A required reduction of two million tons has much smaller impact than a required reduction of five to ten million tons.

- Does the emission reduction have to account for growth in emissions from new sources? -- If the emission reduction applies only to current emission levels from existing sources, its impact is smaller than if additional reduction is required to offset the growth in emissions from new sources and/or

TABLE 3

SUMMARY OF THE PRODUCTION IMPACTS OF SELECTED ACID RAIN ALTERNATIVES IN 1990
(million tons)

Region a/	Actual 1979	Actual 1980	Forecasted 1990 b/	Changes Under Alternative Proposals c/ d/ e/							
				Analyses of Mitchell Bill				Other Analyses			
				#1	#2	#3	#4	#5	#6	#7	#8
Northern Appalachia	188	185	205	(42)	(43)	(33)	(33)	(18)	(12)	(3)	(5)
Central Appalachia	214	233	318	55	50	47	47	23	22	4	5
Southern Appalachia	24	26	31	(4)	(4)	2	(3)	-	(1)	-	-
Midwest	130	134	171	(63)	(51)	(58)	(55)	(28)	(36)	(18)	(10)
West	222	252	527	55	46	40	40	20	22	17	10
Total	778	830	1,251	1	(1)	(2)	(4)	(3)	(6)	-	-

---

a/ See Figure 3 for map of the coal supply regions.

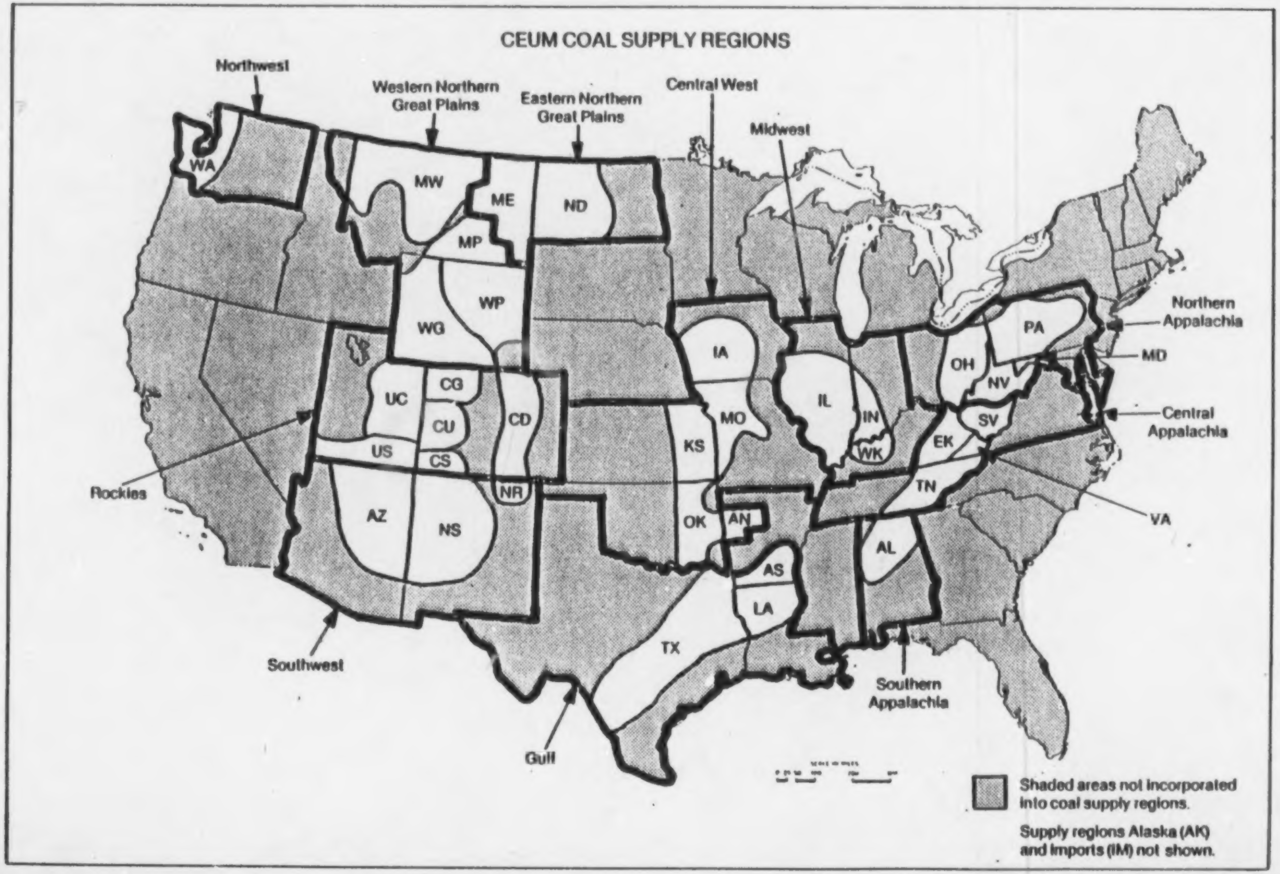
b/ Estimates are forecasted production under assumptions specified by EEI. Forecasts using assumptions specified by EPA/NWF (Alternative # 3, 7, and 8) would be different.

c/ See Page 2 for a description of the alternatives.

d/ Estimates in Table 3 with the exception of alternative #3 all assume no interstate trading. Whether interstate trading is allowed or not does not have a significant impact on regional coal production impacts.

e/ Changes in production are calculated from their respective base cases. Therefore, caution should be exercised in comparing absolute levels of forecasted coal production in 1990 between the EPA/NWF (Alternatives 3, 7 & 8) and the EEI analyses.

FIGURE 3



CEUM COAL SUPPLY REGIONS

Northwest
Western Northern Great Plains
Eastern Northern Great Plains
Central West
Midwest
Northern Appalachia
MD
Central Appalachia
VA
Southern Appalachia
Gulf
Southwest
Rockies
WA
MW
ME
ND
MP
WP
WG
UC
CG
CU
CD
US
CS
NR
AZ
NS
IA
MO
KS
OK
AN
AS
LA
TX
IL
IN
WK
OH
PA
NV
SV
EK
TN
AL

▨ Shaded areas not incorporated into coal supply regions.

Supply regions Alaska (AK) and Imports (IM) not shown.

existing sources. As shown in Table 1, the requirement to offset the growth in sulfur dioxide and nitrogen oxide emissions (between 1980 and 1990) from utility and industrial sources increases the required reduction by about three million tons. A substantial part of this is caused by a forecasted increase in emissions at existing plants between 1980 and 1990 (about 2 million tons after SIP compliance) due to increased capacity factors and switches to higher sulfur coal which is still in compliance with SIP's.

- Do both nitrogen oxide and sulfur dixoide have to be controlled? -- The required sulfur dioxide reduction by utilities increases by about one million tons if emissions of nitrogen oxide from both utility and non-utility sources are not to exceed 1980 levels (assuming a two for one trading ratio).

- Do utilities get credit for SIP compliance? -- If the utiities receive credit for coming into compliance with SIP's, the requred reduction in sulfur dioxide emissions is reduced by about 1.5 million tons.

- Would there be cost-effective reductions in utility nitrogen oxide and/or non-utility sulfur dioxide? -- If the utilities chose to undertake cost-effective reductions in nitrogen oxide emissions (i.e., low nitrogen oxide burners, etc.), the required emission reduction of sulfur dioxide could be reduced by about 0.8 million tons (assuming a two for one trading ratio) to 1.6 million tons (assuming a one for one trading ratio). There would be even less need to reduce sulfur dioxide emissions if some new cost-effective nitrogen oxide control technologies become available. If non-utility sources are either required to undertake cost effective emission reductions for sulfur dioxide (or the utilities elect to pay these sources to reduce emissions), the required emission reduction would be decreased by at least 0.3 million tons.

- Would interstate trading be politically feasible?-- As shown in Table 2, interstate trading can reduce the cost of complying with any of the acid rain alternatives. For emission reductions of less than eight million tons, this savings amount to about $0.5 billion (1982 dollars) per year. For emission reductions greater than 10 million tons, the potential savings of interstate trading is forecasted to be much greater (savings of about one billion dollars per year under a 12 million ton reduction). Despite the cost savings cited above, many have expressed skepticism concerning the real-world viability of interstate trading, noting reasons for institutional and political resistance and the lack of any clear thinking on the institutional, financial, political, and regulatory mechanisms and procedures that would be employed.

CAVEATS AND LIMITATIONS OF ANALYSES

The summary is intended for use by EEI in order to understand how the impacts of acid rain proposals change with the specified levels of emission reduction. To facilitate this analysis, we have included the findings of studies that ICF has done for EPA, NWF, and EEI. While we feel that the findings of these studies can be used to make general conclusions about the magnitude of the cost and coal production impacts at different levels of assumed emission reduction (i.e., 1.7 to 13.1 million tons by 1990), it should be kept in mind that two other factors influence these impacts. These two factors are: (1) assumptions for base case forecasts under current environmental regulations; and (2) assumptions for pollution control costs.

The studies included in this report used different assumptions (based on the clients' specifications) to forecast base case emissions and coal production under current environmental regulations. These different assumptions also effected the estimated impacts of alternative acid rain control strategies on the electric utility and coal industries. For example, the EPA/NWF and the EEI studies have different assumptions for key variables such as electricity growth rates, installed nuclear capacity, level of synfuels development (see Appendix B for comparison of the EPA/NWF and EEI assumptions). Although we feel the differences in the forecasted impacts due to different base case assumptions is of minor importance compared to the factors discussed in the previous section, EEI should be aware of these caveats when interpreting the findings of this report. This is especially true when comparisons are made between forecasted 1990 coal production at the state level under current environmental regulations and forecasted production under alternative acid rain scenarios.

Similarly the estimates of the costs of scrubbers are different in the EPA/NWF and EEI analyses (see Appendix B). These differences in scrubber costs directly affect the annualized cost impacts of the alternative acid rain control strategies.

Another limitation of this summary is that we did not fully address the issue of how alternative schemes of allocating emission reduction liability to each state at any given emissions reduction level would influence the cost and electricity rate impacts on each of the states in the ARMS Region. While there are a large number of ways in which the liability can be allocated, the prinicpal schemes which have been used to date include the following:

- Equal Percent Rollback. This approach requires each state to rollback emissions by an equal amount (i.e., 10 percent, 30 percent, etc.). The states are free to allocate the reduction within the state and to trade reduction liabilities between states. This form of allocation tends to reduce the cost impacts in the midwestern states and to increase the impacts in other regions such as New England.

- Emission caps -- This approach establishes an emission cap on each plant (i.e., 4.0 lbs./MmBtu, 2.0 lbs./MmBtu, 1.2 lbs./MmBtu, etc.). Such an approach is economically less efficient than the rollback approach (with interstate trading) because it does not allow the emission reduction to be allocated in the most cost-effective way. This problem could be eliminated by allowing plants to trade emission liabilities (i.e., one plant only reduces emissions to 2.5 lbs. sulfur dioxide/mmBtu while another reduces emissions to 1.5 lbs. sulfur dioxide/mmBtu) to achieve an average emission rate of 2.0 lbs sulfur dioxide/mmBtu if it was cost-effective to do so.

- Allocation based on each State's percentage of current emissions above some emission rate -- Under the Mitchell Bill, the reduction liability is based on each state's percentage of the total excess emissions in the ARMS region. Excess emissions are defined on a plant by plant basis to be total actual emissions less what emissions would have been if the plant had only emitted at an emission rate of 1.2 lbs. sulfur dioxide/mmBtu. Such an emission liability approach increases the required reduction in midwestern states such as Ohio, Indiana, Kentucky, etc. and reduces the required reduction in other regions such as New England.

It is important to emphasize that, the choice of an emission reduction liability scheme effects the distribution of costs between states significantly. For example, the net cost to Ohio after interstate trading (i.e., after buying and selling of emission reductions) of a 10 million ton reduction would be different if Ohio's initial liability was 1.7 million tons (i.e., as under the Mitchell Bill) or 1.3 million tons (i.e., as under a uniform 60 percent reduction from 1980 levels in each state). Also, assuming that interstate trading is institutionally feasible, the effect of different liability schemes would not affect total costs in the ARMS region, but would reallocate costs between the states.

APPENDIX A

STATE-BY-STATE DETAILS

(To Be Provided)

APPENDIX B

COMPARISON OF BASE CASE AND POLLUTION CONTROL COST ASSUMPTIONS

TABLE B-1

COMPARISON OF MAJOR BASE CASE ASSUMPTIONS

Critical Parameter	EPA/NWF	EEI
Global Energy and Economic Conditions		
• World Oil Prices (Early-1982 $/bbl)	1985 = 44.96 1990 = 51.17 1995 = 59.30 2000 = 70.09	1985 = 41.03 1990 = 45.30 1995 = 50.00 2000 = 55.21
• Natural Gas Prices and Availability	1985 deregulation is assumed	1985 deregulation is assumed
Electric Utility Assumptions		
• Electricity Growth Rate (% per year)	1980-1985 = 3.4 1986-1990 = 3.4 1991-1995 = 2.5 1996-2000 = 2.0	1980-1985 = 3.0 1986-1990 = 3.0 1991-1995 = 3.0 1996-2000 = 3.0
• Nuclear Capacity (Gw)	1985 = 82 1990 = 117 1995 = 140 2000 = 150	1985 = 69 1990 = 107 1995 = 129 2000 = 140
• Substitution of Coal for Oil and Gas	Reconversions: 1981-1990 = 21.2 Gw $2,400/Kw capital surcharge.	Reconversions: 1982-1990 = 17.0 Gw Capital surcharge varies by region.
• Utility Generation Plant Capital Costs (Early-1982 $/Kw)	Coal = 824 - 1,039 Nuclear = 1,207 - 1,403 Turbine = 244 - 257	Coal = 876 - 1,010 Nuclear = 1,224 - 1,505 Turbine = 268 - 282
• Pollution Control Capital Costs (Early-1982 $/Kw)	Scrubbers, Dry = 138 Scrubbers, Wet = 246 - 274	Scrubbers, Dry = 174 - 190 Scrubbers, Wet = 259 - 274
Non-Utility Coal Demand		
• Industrial Coal Use (Million Tons)	1985 = 116 1990 = 195 1995 = 305 2000 = 410	1985 = 89 1990 = 134 1995 = 192 2000 = 293

TABLE B-1
(Continued)

COMPARISON OF MAJOR BASE CASE ASSUMPTIONS

Critical Parameter	EPA/NWF	EEI
Non-Utility Coal Demand (Continued)		
• Residential/Commercial Coal Use (Million Tons)	1985 = 8 1990 = 9 1995 = 10 2000 = 11	1985 = 8 1990 = 9 1995 = 10 2000 = 11
• Coal Exports (Million Tons)		
-- Steam Coal	1985 = 33 1990 = 56 1995 = 84 2000 = 124	1985 = 50 1990 = 90 1995 = 137 2000 = 189
-- Metallurgical Coal	1985 = 50 1990 = 58 1995 = 68 2000 = 78	1985 = 50 1990 = 55 1995 = 55 2000 = 55
• Domestic Metallurgical Coal Use (Million Tons)	1985 = 79 1990 = 80 1995 = 84 2000 = 78	1985 = 73 1990 = 67 1995 = 66 2000 = 62
• Synthetics (Coal Input)	1985 = 0.417 Quads 1990 = 0.830 Quads 1995 = 1.670 Quads 2000 = 3.340 Quads	1985 = 6 Tons 1990 = 25 Tons 1995 = 53 Tons 2000 = 77 Tons
Financial Parameters		
• Inflation Rate (% per year)	1981-2000 = 9.0%	1981-1985 = 8.0% 1986-1990 = 7.5% 1991-1995 = 7.0% 1996-2000 = 6.5%

TABLE B-1
(Continued)

COMPARISON OF MAJOR BASE CASE ASSUMPTIONS

Critical Parameter	EPA/NWF	EEI
Financial Parameters (Continued)		
• Real Discount Rates (% per year)	Coal Mine = 6.00% Utility = 4.26%	Coal Mine = 6.00% Utility = 4.27%
• Coal Transportation Rates -- Rail, Barge and Truct (% total real escalation)	1979-1985: East = 25.0% West = 33.0% 1986-2000 = 0.0%	1981-1985: East = 25.0% West = 25.0% 1986-2000: = 0.0%
• Mining Costs (% annual real escalation)	Capital = 0.0% Labor = 1.0% Materials = 1.0%	Capital = 0.0% Labor = 0.0% Materials = 0.0%
• Capital Charge Rates		
Coal/Nuclear/Combined Cycle	10.0%	9.0%
Scrubbers/Particulate Equipment	12.5%	11.5%
Combustion Turbines	12.5%	10.5%
Other Governmental Regulations		
• Federal Leasing Policy	Enough	Enough
• Air Pollution Regulations	Most recent federal and state rules.	Most recent federal and state rules.

STATEMENT OF DR. LARRY PARKER, ANALYST IN ENERGY POLICY
ROBERT E. TRUMBULE, SPECIALIST IN ENERGY POLICY
ENVIRONMENT AND NATURAL RESOURCES POLICY DIVISION,

REGARDING THE COSTS OF PROPOSED REDUCTION IN ACID RAIN PRECURSORS

We appreciate this opportunity to discuss our work in the area of acid rain mitigation costs. Rather than discuss the details of SO2 removal costs, we wouldj prefer to summarize the areas of consensus regarding SO2 removal costs as envisioned by the proposed legislation, and then focus on some of the other factors not yet studied in any great detail which could affect these costs.

Our review of current cost studies indicate that the annualized costs in 1990 of a 10 million ton reduction of SO2 range from $2.5 to $4.6 billion (mid 1980 dollars). Work done by OTA, DOE, and ICF (both for the National Wildlife Federation and the Edison Electric Institute) falls within this range. Ten States would pick up the lion's share of the costs of the proposed reduction program: Illinois, Indiana, Kentucky, Michigan, Missouri, Ohio, Pennsylvania, Tennessee, West Virignia, and Wisconsin. However, with the exception of Pennsylvania, these States would still enjoy lower electricity rates than the Mid-Atlantic or New England States even with the proposed reduction program. As projected by ICF, this is true both in terms of 1980 electricity rates and projected 1990 electricity rates. (See Charts 1 and 2)

Part of the difficulty in reviewing acid rain mitigation costs is that there is no one acid rain bill. Some bills contain a cap on total emissions, some do not. Some bills provide for SIP credits in determining the reduction assessments, some do not. Finally, the bills present a variety of interstate or regional trading possibilies. Such provisions add uncertainty regarding how much SO2 or NOx each State has to remove.

Indeed, we have yet to see two studies which agree on this point.

Beyond this question of how much reduction is allocated to the various States is the selection and cost of the various removal technologies. The lower-cost projections generally assume that a considerable portion of the reduction goal will be met through fuel switching, a rather cost-effective alternative. Higher-cost studies, such as the American Electric Power (AEP) study, provide for little fuel switching and rely primarily on FGD and premature retirement of generating facilities with kilowatt for kilowatt replacement with new facilities to remove the necessary SO2. This question is sufficiently complex that the DOE study did not even attempt to analytically determine the alternative mix, making it an assumption of the study instead.

Also, within each alternative, the costs differ across the various studies. For example, ICF, in calculating FGD costs assumes a capacity and energy penalty for scrubbers at about 3 to 5 percent, based on EPA data. AEP, however, assumes a capacity loss of 10 percent. In the case of AEP, this cost is further escalated by assuming that this loss capacity has to be replaced kilowatt for kilowatt by new capacity. The scrubber cost differences extend into capital cost and operations and maintainance costs assumptions. This is not unique to FGD, other alternatives, such as fuel switching, also have cost differences among the studies. Finally, comparison of cost estimates of the various studies is complicated by differing cost accounting conventions and financial assumptions (interest rates, depreciation, etc.).

It is important to noted that all of the studies above are based on one scenario: reduction of SO2 by utilities. This is not an unreasonable scenario: utilities are a primary sources of SO2 and SO2 is the precursor most prominantly mentioned in the acid rain bills. Also, these studies tends to rely primarily on four reduction alternatives: fuel switching, coal cleaning, FGD, and premature retirement of plants. However, this scenario is not mandated by the acid rain bills. Utilities are not required to reduce SO2 emissions; States are required to reduce SO2 or NOx in a 2 for 1 ratio by a certain amount, depending on the specific bill. The bills provide States with considerable flexibility in meeting their objectives. We feel this critical flexibility has been lost in these stduies as analysts have attempted to define a scenario which is easily measureable.

One feasible alternative not considered is the cost-effective reduction of SO2 emissions from industrial sources. Between 20 and 25 percent of all SO2 emissions in the United States come from industrial boilers and process heaters. These emissions represent a significant pool for States to consider in designing compliance programs.

Industrial emissions reduction could be of particular importance to some of the higher-emitting States in reducing the impact of the proposed program on the utilities. As shown Chart 3, all of the States in the proposed reduction program have significant industrial SO2 emissions relatives to their utility emissions, In particular, Ohio, Indiana, Illionis, Pennsylvania, Wisconsin and Michigan have industrial emissions equal to or greater than 20 percent of their total SO2 emissions, Depending on a State's compliance program, this potential could either reduce the States' cost of compliance by employing a cost-effective criterion, reduce the burden on utilities by focusing on industrial emissions, or both by combining the criteria.

Besides SO2, both utilities and industry emit millions of tons of NOx annually. As noted, the acid rain bills before the committee permit the substitution of NOx for SO2 in a ratio of 2 to 1. However, no study has yet assessed the potential for cost-effective NOx removal in meeting the 10 million ton reduction. Indeed, EEI restricted its analysis from including NOx removal, and AEP did not include the NOx reduction that would occur by the replacing old plants with new generating facilities which would the NSPS for NOx.

The United States produces about 22.2 million tons of NOx per year, compared with about 29.6 million tons of SO2. Of this amount, about 9.0 million tons is produced by the transportion sector. Of the remaining 13.2 million tons, 6.2 million tons is produced by utilities and 7.0 million tons is produced by industry and residential/commercial sectors. About 85 percent of these emissions is produced in the eastern part of the country, and therefore represent an additional source of reductions for States.

As noted by the Electric Power Research Insitute (EPREI), methods exist now or are only a few years away from commercial application which can permit NOx emissions "significantly lower than todays standards at costs only incrementally higher." These methods include combustion modification techniques and use of low nitrogen fuel, both of which reduce the formation of NOx during the burning, and wet and dry processes which remove NOx from flue gas after combustion has occurred. Indeed, costs for Nox removal do not escalate sharply until one reaches beyond the 70 to 80 percent removal level. Even with the 2 for 1 ratio provided for in the various bills, considerable opportunities exist for cost-effective controls of NOx.

The inclusion of potential industrial and NOx emissions increases the pool of available emissions to be reduced and the diversity of emission sources. Besides potentially lowering the cost of the reduction program, this large pool of emissions could lessen the burden of such a program on the utility industry and therefore the ratepayers. Lessening this burden could be important to the success of any reduction program because of the current financial situation of the utilities. Utilities are a very capital intensive industry and with current and projected electricity demand down from its historic trend are in an overbuilt and overcapacity situation. This, coupled to the reluctance of regulators to increase rates to levels the utilities believe necessary, has resulted in a strained financial situation for many companies. To require more capital expenditures in this situation, combined with the current interest rates, would make the situation even more bleak.

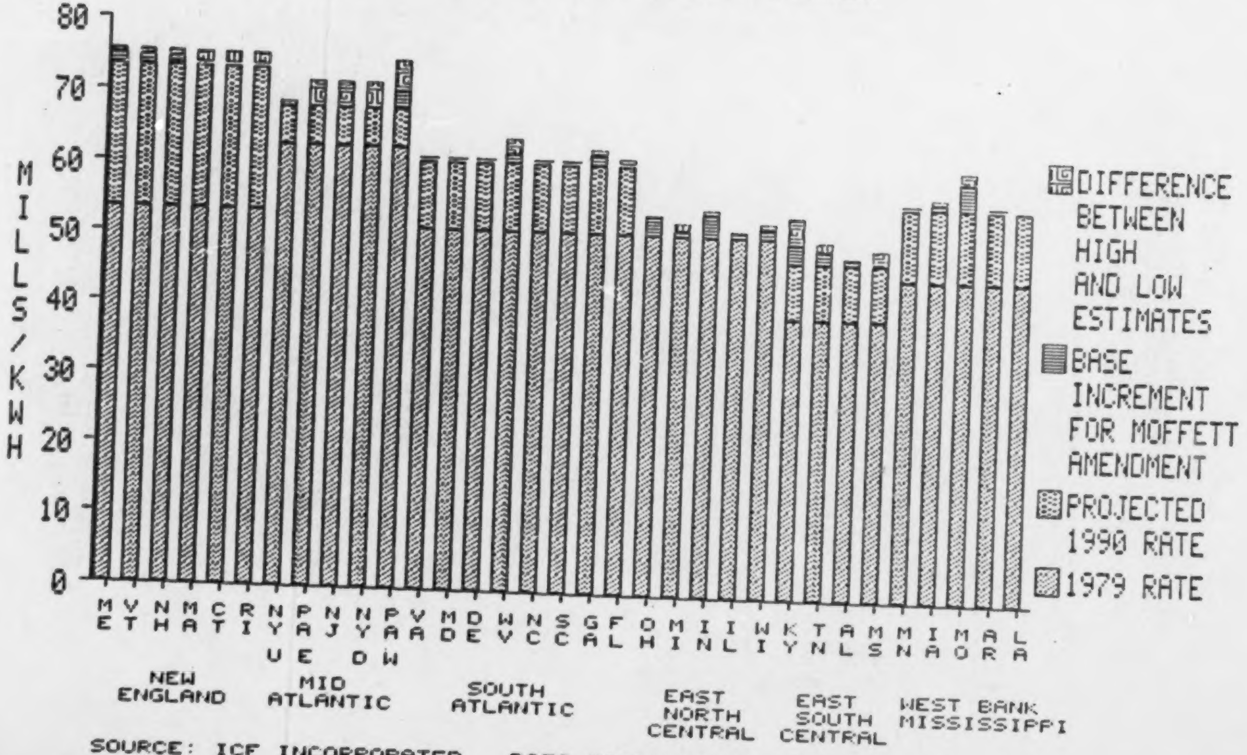
A difference aspect of State flexibility which could drive up the cost of a reduction program in individual States would be a State requirement for existing industrial and utility facilities to use local, high sulfur coal. Fuel switching to low sulfur coal is one of the more cost-effective techniques for reducing SO2 emissions. Hence, States in the Midwest and parts of Appalachia may decide to trade strict cost-effectiveness for protection of their local high sulfur coal industry. Such a requirement might force these industries and utilities to employ other, more expensive techniques in order to reduce emissions.

Finally, there are several alternatives mentioned in bills--energy conservation, least emissions dispatching, and others--which have not be evaluated. Admittedly, it is not clear how some of these alternatives could be implemented, but the options do exist.

To conclude, current information suggests that a 10 million ton reduction of SO2 by utilities would incur an annualized cost in 1990 of between $2.5 and $4.6 billion (mid-1980 dollars). However, States have the flexibility under the proposed bills to raise or lower the cost of compliance through other alternatives and methods not studied in these reports. How States choose to use the flexibility these bills grant them will utimately determine the cost of any reduction program.

CHART 1

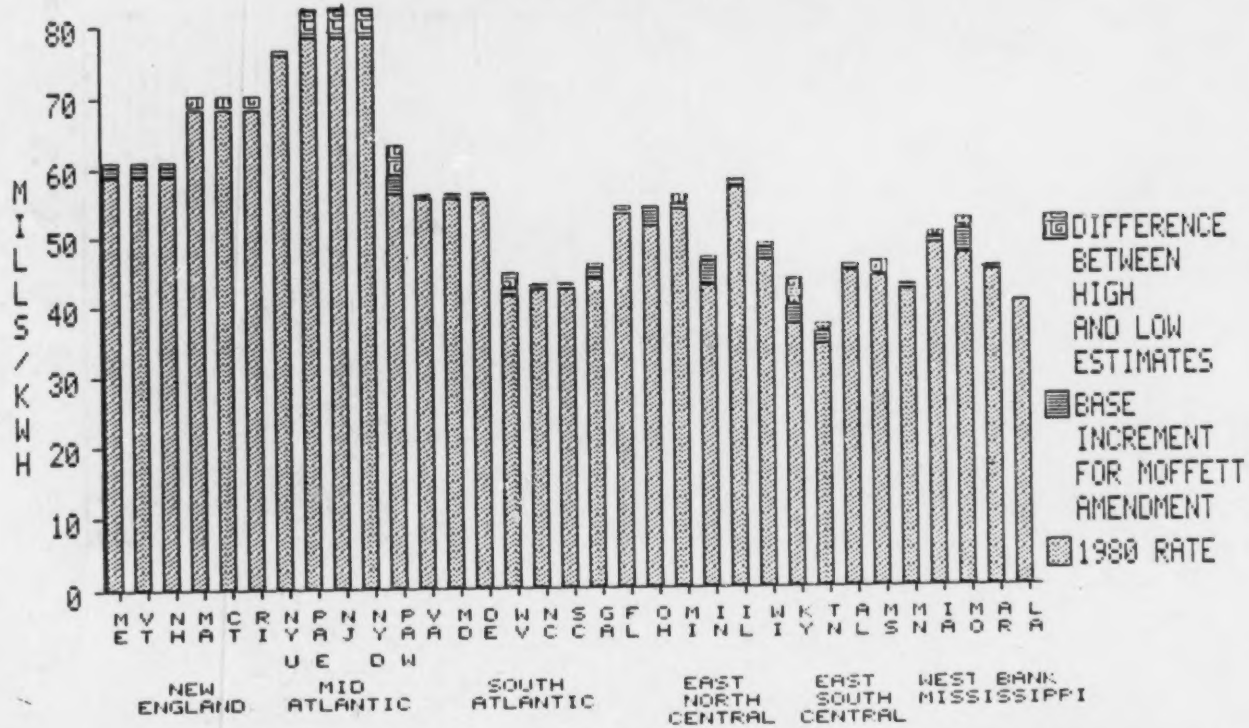
COMPARISON OF COST ESTIMATES FOR MOFFETT AMENDMENT:
COMPARATIVE ELECTRICITY RATES FOR 1990
(ANNUALIZED COSTS, MID 1980 DOLLARS)



SOURCE: ICF INCORPORATED DATA COMPILED BY CRS

CHART 2

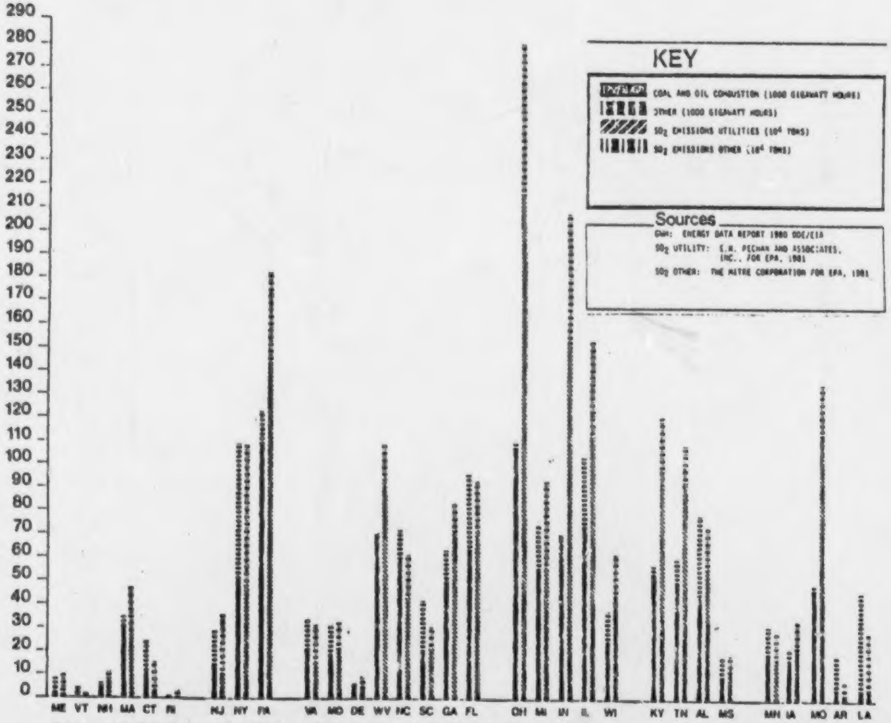
COMPARISON OF COST ESTIMATES FOR MOFFETT AMENDMENT:
CHANGE IN ELECTRICITY RATES IN 1990 (FROM 1980 LEVELS)
(ANNUALIZED COSTS, MID 1980 DOLLARS)



SOURCE ICF INCORPORATED DATA COMPILED BY CRS

CHAI

ACID RAIN CONTROL AREA EMISSIONS
Eastern Power Generation and SO_2 Emissions



Data complied by the Natural Resources Defense Council

STAFF BRIEFING MEMO

By the Office of Technology Assessment

for the

Senate Committee on Environment and Public Works

June 2, 1982

(Revised June 4, 1982)

This material has not been reviewed nor approved by the

Technology Assessment Board

I. Sulfur Dioxide Emissions Inventory.

For 1980, sulfur dioxide emissions in the 31 eastern state region were estimated to be approximately 22.5 million tons. Utility sulfur dioxide emissions were estimated to be about 16 million tons, or about 70% of the total. Non-utility emissions (including industrial combustion, residential and commercial combustion, and industrial process emissions from refineries, iron and steel producers, and smelters, among others) comprised the remaining 6.5 million tons or 30% of the total.

Table 1 presents 1980 sulfur dioxide emissions, and the percent contributed by utilities, by state. A more detailed emissions inventory is presented in the appendix.

II. Emissions Reductions Specified by the Bills.

1. S. 1706, the "Mitchell Bill".

The Mitchell bill requires that the amount of sulfur dioxide and nitrogen oxides emitted from the eastern 31 states and D.C. not exceed the amount of each of these pollutants emitted from the region as of January 1, 1981. Moreover, the bill requires that within 10 years of enactment, sulfur dioxide emissions from the eastern region be reduced by 10 million tons. OTA interprets the Mitchell Bill to be a one-time reduction; i.e., new source growth need not be offset by additional emissions reductions from existing sources.

S. 1706 also specifies the amount by which each state must reduce its sulfur dioxide emissions. This reduction is defined as a fraction of the 10 million ton target. The fraction is stated entirely in terms of utility emissions.[1]

Table 2 presents the sulfur dioxide emission reduction by state, as allocated by S. 1706. The first column shows 1980 emissions by state, and the second column displays the reductions in 1980 sulfur dioxide emissions required by the bill. However, it is important to note that under current laws and regulations embodied in State Implementation Plans (SIPs), some states are presently required to decrease their sulfur dioxide emissions. In fact, approximately 1.5 of the 10 million ton reduction specified by S. 1706 is already required under existing SIPs. Column 3 shows the reductions in

Table 1

1980 Eastern U.S. SO_2 Emissions (10^3 Tons)

State	State Total	% Utilities
Alabama	⑬ 739.8	76%
Arkansas	㉙ 78.9	34%
Connecticut	㉕ 149.1	22%
Delaware	㉘ 90.8	58%
District of Columbia	44.4	10%
Florida	⑩ 933.7	78%
Georgia	⑫ 837.7	87%
Illinois	④ 1532.8	74%
Indiana	③ 2079.8	74%
Iowa	⑱ 344.3	68%
Kentucky	⑥ 1108.0	89%
Louisiana	㉓ 260.5	10%
Maine	㉗ 98.4	17%
Maryland	⑲ 330.0	68%
Massachusetts	⑯ 477.7	58%
Michigan	⑪ 931.7	61%
Minnesota	㉒ 294.0	61%
Mississippi	㉔ 196.1	67%
Missouri	⑤ 1348.6	85%
New Hampshire	㉖ 109.0	74%
New Jersey	⑰ 362.0	30%
New York	⑨ 1078.9	45%
North Carolina	⑮ 618.5	71%
Ohio	① 2802.6	77%
Pennsylvania	② 2165.6	67%
Rhode Island	32.1	16%
South Carolina	㉑ 315.6	70%
Tennessee	⑧ 1086.0	86%
Vermont	15.0	3%
Virginia	⑳ 326.7	50%
West Virginia	⑦ 1093.6	87%
Wisconsin	⑭ 618.8	72%
TOTALS	22,500.7	71%

Source: Phase III (Final) Emissions Inventory by U.S./Canada Work Group 2, Report No. 2-B (Draft), September 4, 1981.

Table 2

SO_2 Emission Reductions Required by the Mitchell Bill (10^3 Tons)

State	State Total	Target Reductions Before SIP Compliance	Final Target Reductions After SIP Compliance
Alabama	739.8	303.5	194.1
Arkansas	78.9	0.6	0.0
Connecticut	149.1	0.0	0.0
Delaware	90.8	16.9	16.9
District of Columbia	44.4	0.0	0.0
Florida	933.7	340.6	322.7
Georgia	837.7	452.6	436.4
Illinois	1532.8	770.2	741.9
Indiana	2079.8	1191.3	1028.8
Iowa	344.3	128.9	108.6
Kentucky	1108.0	696.8	457.9
Louisiana	260.5	0.0	0.0
Maine	98.4	2.7	2.7
Maryland	330.0	109.8	109.6
Massachusetts	477.7	106.4	71.6
Michigan	931.7	238.2	190.1
Minnesota	294.0	67.0	66.8
Mississippi	196.1	73.3	73.3
Missouri	1348.6	911.1	911.1
New Hampshire	109.0	50.1	37.5
New Jersey	362.0	38.2	38.2
New York	1078.9	226.5	193.3
North Carolina	618.5	89.0	89.0
Ohio	2802.6	1617.5	1335.0
Pennsylvania	2165.6	876.7	750.9
Rhode Island	32.1	0.0	0.0
South Carolina	315.6	97.0	97.0
Tennessee	1086.0	679.0	423.6
Vermont	15.0	0.1	0.1
Virginia	326.7	26.0	26.0
West Virginia	1093.6	582.4	561.7
Wisconsin	618.8	308.1	306.7
TOTALS	22,500.7	10,000.0	8,591.2

Source: Office of Technology Assessment

emissions required beyond those needed to comply with the provisions of existing laws and regulations.

Under the bill, the mandated decreases in state sulfur dioxide emissions can be achieved in different ways. The reduction can come from any source -- utility or non-utility -- within the state, from another state if an agreement can be reached, or by reducing two tons of nitrogen oxide emissions for each ton of sulfur dioxide.

2. S. 1709, the "Moynihan Bill".

The Moynihan bill is similar to the Mitchell bill in that it specifies the same eastern state region and allows states the same flexibility in implementing reductions. However, the Moynihan bill differs from the Mitchell bill in that it does not specify sulfur dioxide emissions reduction by tonnage. Rather, the emissions reduction target is a percentage of actual emissions from only the largest electric-generating plants -- which we estimate to include about 60 plants located in about half the states in the 31 state region.[2]

OTA estimates that the sulfur dioxide emission reductions specified by the bill are about 6.7 million tons.[3] As mentioned previously, a 1.5 million ton reduction in sulfur dioxide emissions is already required by existing SIPs. Therefore, the total decrease in emissions achieved under the bill is about 8.2 million tons of sulfur dioxide.

Table 3 illustrates the required sulfur dioxide emission reductions, by state, for S. 1709. The first column shows 1980 emissions and the second column displays the reductions in 1980 sulfur dioxide emissions required by the bill.

III. Regional Costs.

Rather than making single estimates of the costs of the Mitchell and Moynihan bills, a range of estimates corresponding to different assumptions as to how the emission reductions might be accomplished at the state level is presented. The costs of the emissions reductions specified by the Mitchell bill are estimated to range from \$3.3 to \$4.1 billion per year. The costs associated with the Moynihan bill range from an estimated \$2.2 to \$2.6 billion per year. These costs are first year, annualized costs in 1979 dollars.

Table 3

SO_2 Emission Reductions Required by the Moynihan Bill (10^3 Tons)

State	State Total	Emissions Reductions Specified by Bill
Alabama	739.8	107.0
Arkansas	78.9	0.0
Connecticut	149.1	0.0
Delaware	90.8	0.0
District of Columbia	44.4	0.0
Florida	933.7	256.7
Georgia	837.7	269.0
Illinois	1532.8	596.9
Indiana	2079.8	1011.7
Iowa	344.3	0.0
Kentucky	1108.0	547.1
Louisiana	260.5	0.0
Maine	98.4	0.0
Maryland	330.0	0.0
Massachusetts	477.7	0.0
Michigan	931.7	55.7
Minnesota	294.0	0.0
Mississippi	196.1	56.0
Missouri	1348.6	749.5
New Hampshire	109.0	44.5
New Jersey	362.0	0.0
New York	1078.9	44.2
North Carolina	618.5	0.0
Ohio	2802.6	1208.0
Pennsylvania	2165.6	648.3
Rhode Island	32.1	0.0
South Carolina	315.6	0.0
Tennessee	1086.0	508.6
Vermont	15.0	0.0
Virginia	326.7	0.0
West Virginia	1093.6	535.9
Wisconsin	618.8	49.3
TOTALS	22,500.7	6688.2

Source: Office of Technology Assessment

To facilitate comparison of these costs analyses, Figure 1 presents a graph of the cost estimates for the Mitchell and Moynihan bills, and a series of emissions caps or limits ranging from 1.0 to 4.0 pounds of sulfur dioxide per million Btu of fuel used. It should be noted that these estimates do not include the cost for emissions reductions required under current law.

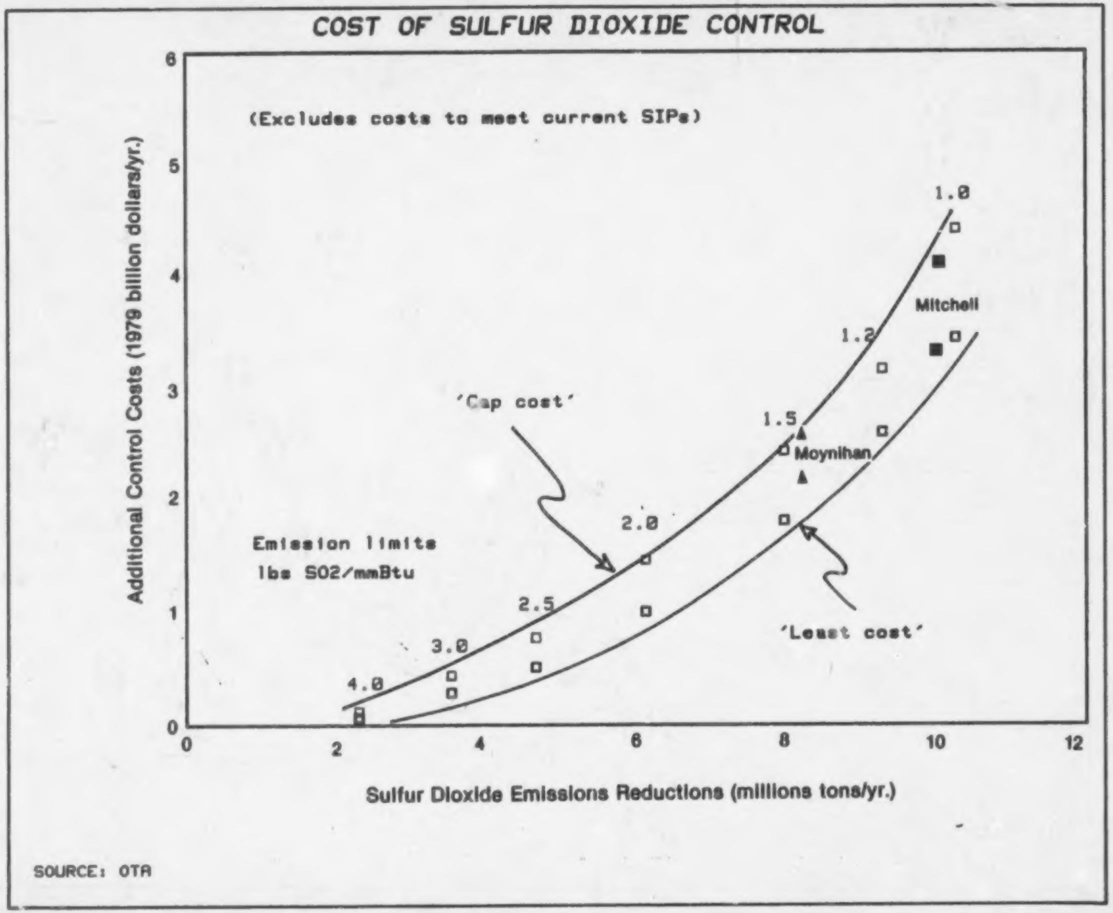
A line joining two symbols indicates the range of costs which might be associated with the specified emission reduction. The upper estimate assumes that each state would achieve required reductions by imposing uniform emission ceilings on utility plants. The lower estimate assumes that each state will choose the most cost-effective way of meeting the required emission reductions. This might occur by some intra-state trading mechanism or by a state requiring emissions reductions from those plants that can reduce emissions least-expensively. However, no interstate trading occurs.

For comparison, OTA analyzed the costs of a scenario under which emissions reductions would be accomplished by a "least-cost" strategy of achieving reductions in the entire 31-state region through interstate trading. This regional least cost analysis is depicted as the curve on Figure 1. (For emissions reductions less than 2.5 million tons below SIP compliance, e.g., in the 3.0 and 4.0 pound cap area of the graph, we do not believe 'regional least cost' is significantly different than that estimated by a 'state cap'.) This strategy assumes a "perfect market" with total freedom to trade emissions across the entire region. If this least-cost regional approach were possible, the emission reduction targets of the Mitchell and Moynihan bills could be achieved at a cost of $3.1 and $1.7 billion per year (in 1979 dollars), respectively.

These costs vary regionally, of course, depending upon the magnitude of reductions required and the average costs of emissions reductions in each state. Figure 2 presents the percent increase in electricity costs that might result from the Mitchell bill. Because the percent increase depends on the current rates as well as increases due to the bill, Figure 3 presents the ranking of electricity costs within the region before and after emissions reductions required by S.1706.

The cost estimates generated by the computer model we are using must be considered approximate, because we could not fully incorporate the provisions for flexibility in achieving emission reduction specified in both the Mitchell

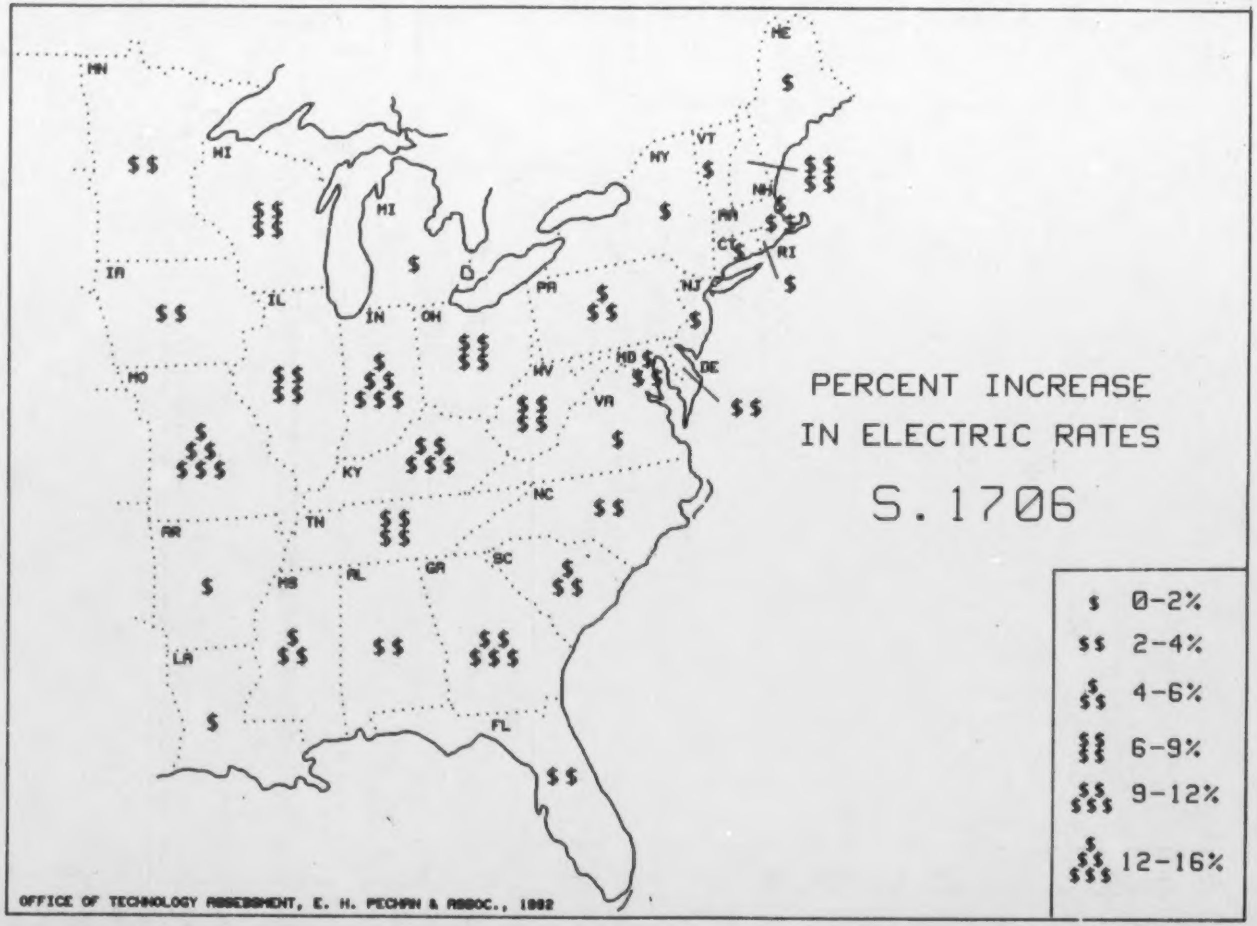
FIGURE 1



COST OF SULFUR DIOXIDE CONTROL

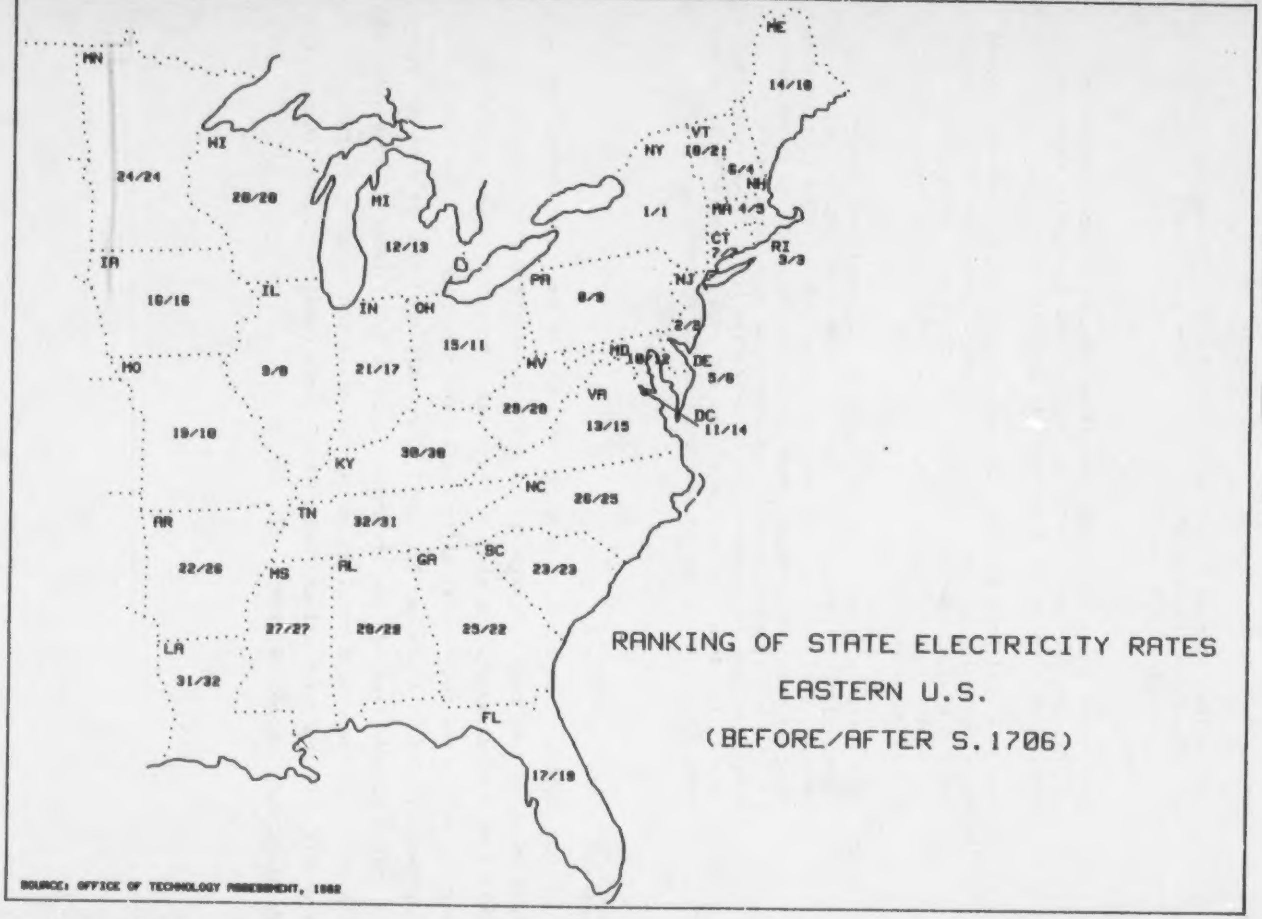
SOURCE: OTA

Figure 2


PERCENT INCREASE
IN ELECTRIC RATES
S.1706
$ 0-2%
$$ 2-4%
$$$ 4-6%
$$$$ 6-9%
$$$$$ 9-12%
$$$$$$ 12-16%
MN
WI
MI
IA
IL
IN
OH
PA
NY
VT
NH
MA
CT
RI
ME
NJ
MD
DE
WV
VA
MO
KY
TN
NC
SC
AR
MS
AL
GA
LA
FL

OFFICE OF TECHNOLOGY ASSESSMENT, E. H. PECHAN & ASSOC., 1982

Figure 3


MN
24/24
WI
20/20
MI
12/13
IA
16/16
IL
9/8
IN
21/17
OH
15/11
MO
19/18
KY
30/30
AR
22/26
TN
32/31
MS
27/27
AL
29/29
GA
25/22
SC
23/23
NC
26/25
LA
31/32
FL
17/19
WV
28/28
VA
13/15
PA
8/9
NY
1/1
VT
18/21
NH
6/4
MA
4/5
CT
7/7
RI
3/3
ME
14/10
NJ
2/2
MD
10/12
DE
5/6
DC
11/14

RANKING OF STATE ELECTRICITY RATES
EASTERN U.S.
(BEFORE/AFTER S.1706)

SOURCE: OFFICE OF TECHNOLOGY ASSESSMENT, 1982 and Moynihan bills. The constraints of our analysis follow:[4]

1. Only sulfur dioxide emissions are considered. Though the bills specify a substitution of two tons of nitrogen oxides for one ton of sulfur dioxide, OTA cannot yet analyze the costs of this type of trade.
2. Only utility sulfur dioxide emissions reductions are considered. OTA has not yet examined the potential cost savings of emissions reductions obtained from non-utility industries.
3. Existing utilities are the only sources considered, and are assumed to be operating at their current percent of capacity utilization. The OTA analysis assumes that all reductions are accomplished immediately without accounting for new plants being built, or old plants being retired.
4. Only a finite list of control alternatives, employed singly or in combination, is considered. This includes a variety of fuel-use changes, coal washing, and wet and dry scrubbers. The current model analysis does not consider some of the control strategies mentioned in both bills, such as early retirement of major sources or reductions due to conservation or selective use of lower-emitting plants; likewise, the analysis does not consider the effects of new technologies which may be available within a decade.

IV. Some Further Comments

For comparison to other studies of the costs of emissions reductions, we [illegible] included some representative costs for alternative sulfur dioxide emissions control approaches used in the model. Scrubber capital costs for various unit sizes and removal efficiencies are presented in Table 4. Representative cost increases for low-sulfur coal, expressed as cost per pound of sulfur dioxide removed, are presented in Table 5. Further documentation of the emissions reductions required by the two bills can be found in the appendix, and the OTA testimony before the Senate Committee on Environment and Public Works, October 29, 1981.

Table 4

RETROFITTED LIMESTONE FGD SYSTEM
TOTAL INVESTMENT COST
6 LB. SO_2/MMBtu - No Spares
(1979 $)

MW	% REMOVAL	INVESTMENT $X 10^6	$/KW
500	90	87.47	175
	70	69.91	140
	50	48.40	97
200	90	42.33	212
	70	32.46	162
	50	28.86	129
100	90	26.75	268
	70	23.13	231
	50	17.80	178

Source: Adapted from MITRE Corporation (1981), "Acid Rain Mitigation (ARM) Study Final Utility and Industrial Boiler FGD Costs and Derived Cost Algorithms".

Table 5

Sulfur Differentials Used in AIRTEST and Actual 1980 Values

Differential in 1979 Cents Per Pound SO_2

State	AIRTEST	1980 Form 423*
Ohio	22	7
Texas**	4	39
Pennsylvania	27	***
Illinois	11	14
Indiana	11	8
West Virginia	25	8
Kentucky	10	8
Missouri	17	5
Michigan	11	8
North Carolina	21	5

* Actual values converted to 1979 dollars.

** State not part of ARMS region.

*** No relationship could be derived.

Source: Statistical Analyses of AIRTEST inputs and 1980 Form 423 shipment data.

RESPONSES FROM THE OFFICE OF TECHNOLOGY ASSESSMENT

Answers to Questions Asked by the Committee:

I. How were emission reductions calculated?

As discussed in the briefing memo, several alternative scenarios were run: S. 1706, S. 1709, (under a variety of assumptions about how the bill might be implemented by states) and 4.0, 3.0, 2.5, 2.0, 1.5, 1.2 and 1.0 lb. SO_2/million Btu emission limits. State-by-state reduction estimates (and details of the calculations) for S. 1706 and S. 1709 are included in the briefing memo. Our estimates of 1980 emissions, by sector, are also included.

For all OTA scenarios:

1. New source emissions are not offset from existing source emissions.

2. NO_x for SO_2 trades are not included due to a lack of a credible data base on emission rates and cost of control.

3. Industrial emissions are not considered, again due to the lack of a credible data base on emission rates and cost of control.

4. No absolute ceiling is imposed by the model.

II. How were reduction alternatives chosen?

Reduction alternatives were chosen on the basis of least-cost to the utility (as a levelized cost calculation). For oil-fired boilers, reduction alternatives include oil desulfurization and switching to lower sulfur-content oil. For coal-fired boilers, the cost of over forty alternatives are calculated. These include the following fuel alternatives: the current coal, the current coal cleaned, any of nine alternate coals, and a blend of the current coal with any of the nine alternate coals. The cost of both wet and dry scrubbers are evaluated for each of the fuel alternatives except the nine blended alternatives. Costs of additional particulate control are added when appropriate.

For the scenarios specifying a plant-level emission limit, each of those over forty alternatives are tested and the least-cost alternatives are calculated for seven emissions limits (4.0, 2.0, 1.5, 1.0, 0.8 and 0.6 lbs SO_2/million Btu) for each boiler in the state or region. The most cost-effective alternatives are chosen until the target emissions reduction is met.

Because of the large number of alternatives considered, we did not keep a running total of reductions by each method.

III. What is the average cost per ton of SO_2 for each alternative?

Representative scrubber costs and premiums for low sulfur fuel are presented in the briefing memo. We use a capital recovery factor of 16.5% per year. We do not include the cost of new plant construction to compensate for scrubber capacity and energy penalties.

Our regional cost estimates are first year, annualized costs. This includes a fixed charge rate on capital (i.e., 16.5% of capital costs) and all noncapital expenditures (e.g., fuel costs, operating and maintenance costs) as they might occur in the first year of operation (i.e., without any assumptions about real price increases). Though the pollution control alternatives are chosen on the basis of levelized costs (which include the effects of inflation and real price increases), we report the results as first year annualized costs to remove the effects of macro-economic assumptions from the cost estimates. We do not include the costs to reach SIP compliance.

In the levelized cost calculations (used to choose the alternative) we have used an 8% inflation rate, a 1.5% real annual fuel price increase, and a 0% real annual O&M cost increase.

IV. How were rate increases calculated?

Total costs per state were divided by electricity generated in the state from fossil-fuel plants. The resulting cost increase (in mills/kwhr) was compared to electricity rates in each state as reported by DOE. Data from 1979 were used for all calculations for consistency.

V. Please report any sensitivity analyses.

A range of scenarios, from a 4.0 to 1.0 lb. SO_2/million Btu emission limit, implemented in a variety of ways, is presented in the briefing memo.

VI. Please indicate which of your assumptions differed from the enclosed list of CBO assumptions.

Because we use a different model than the CBO analysis, most of the assumptions listed are not applicable. The model we use is a "state" model, that is, all the analyses relate to existing plants and current conditions. We use this type of model for several reasons:

1) Emissions from existing power plants will dominate U.S. utility sulfur dioxide emissions through at least the year 2000, unless emissions reductions or early retirements occur at those plants. Moreover, the greatest potential for sulfur dioxide emissions reductions comes from existing plants. Thus, in choosing a model, we decided to eliminate the additional complexities of considering new source growth and opted for additional detail on pollution control alternatives available to existing plants.

2) Previous studies indicated that the major factors influencing the costs of emissions reductions are: a) the magnitude of emission reductions, b) the method for allocating reductions to states or to individual plants, and c) the costs of the various control alternatives. This is substantiated by the types of analyses presented

by the utilities. We intentionally used recent historical data whenever possible to eliminate the need for making assumptions about future economic conditions. We have attempted to concentrate on the above three factors using current data to avoid obscuring the effects of proposed acid rain control measures under a blanket of assumed future conditions.

STATEMENT

BY

CHRIS FARRAND
VICE PRESIDENT, GOVERNMENT RELATIONS
PEABODY COAL COMPANY

ON

S. 1706

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

WASHINGTON, D. C.

JUNE 2, 1982

My name is Chris Farrand. I am Vice President of Peabody Coal Company. In October of last year, Peabody attempted to determine the economic impacts of the acid rain mitigation program outlined in S. 1706. In preparing our analysis of the legislation, we concentrated on the bill's effect on consumer cost as well as dislocations in mine-related employment. We attempted to predict its impact based on the lowest cost utility sector response, which is to assume that utilities will choose to substitute fuels rather than retrofit existing facilities with flue-gas desulfurization (FGD) equipment in order to meet the required SO_2 reduction quotas. I want to emphasize that our analysis is based on this fuel-switching scenario. While it may be unrealistic to assume that in every case the reduction quotas will be met by switching low-sulfur fuel, it has been our experience that where it is at all feasible, utilities will switch fuels rather than retrofit new technology to existing plants. The reasons for this predilection are many: technical adaptability problems, lack of physical space and disposal sites, capital constraints, and regulatory disincentives.

This fuel-switching assumption leads to economic impacts which are conservative in terms of consumer costs, but may result in higher levels of mine and mine-related job dislocations.

We will be happy to discuss the method of analysis in detail, but there are a number of significant factors in our analysis which I would like to enumerate.

1. Our calculations do not account for the effects of economic growth during the intervening years until 1990 or until the 10-million-ton reduction in annual SO_2 loadings must be achieved. We find the bill ambiguous about whether the requirement is to reduce emissions below the current level or below the projected 1990 level. If the latter is the case, then the economic impacts would be higher than those we have projected.

2. No attempt was made in our analysis to account for the effects of inflation. All cost estimates are in 1980 dollars.

3. No measurement was made of the additional price effects due to a surge in demand for regionally limited supplies of low-sulfur fuels and limited transportation capacity to accommodate large-scale shifts in fuel sources. This factor could be extremely significant. For example, a 10 percent increase in low-sulfur coal prices would result in at least a 40 percent increase in the economic impact of S. 1706.

4. Our analysis assumes that wherever possible low-sulfur coal of comparable heat value will be substituted. If substantially lower BTU coal is substituted, additional tonnage would have to be purchased, with commensurate cost impacts.

5. Where low-sulfur, low-BTU western coals can be substituted, boiler modifications and particulate emission control equipment would have to be added to existing plants. This factor was not considered in our analysis; it would result in higher costs than we have anticipated.

6. Our analysis calculates the amount of acceptable coal

required for blending to the precise emission requirements. No margin of safety for coal variability is assumed. Overblending to provide a margin of safety would result in higher tonnage displacement.

7. No assumption was made to reflect the effects of production cutbacks on the economic viability of individual mines. A reduction in deliveries from an individual mine may render the entire mine uneconomic to operate.

Under these assumptions, Peabody has estimated the fuel cost impact of the proposed 10-million-ton reduction in annual SO_2 emissions to be approximately $3.2 billion in 1980 dollars. Inflated to account for present dollars, the cost would exceed $4 billion annually. Attached to my October 29 testimony is a state-by-state breakdown of these costs.

From the standpoint of employment impact, our analysis finds there would be severe dislocation in coal mine and mine-related employment. Under our fuel-switching scenario, some 307 million tons of coal valued at approximately $9 billion annually would be displaced to meet the bill's requirements. This loss of high and medium-sulfur coal production would severely impact a number of large coal producing states such as Illinois, Ohio, Kentucky, Pennsylvania, Indiana, Missouri, Alabama, and West Virginia. However, in the case of West Virginia and Kentucky, losses in production in one part of the state may be offset by gains in low-sulfur production in other parts of those states.

Our analysis estimates that 75,149 direct mining jobs would be lost in the Midwest and the higher sulfur coal producing regions of Appalachia. In addition to these direct mining jobs, indirect employment would also be affected because of massive coal producing shifts. Using a multiplier derived from Department of Commerce figures, we now estimate that the total employment dislocation would amount to approximately 300,000.

These job impact calculations are based on average coal productivity in each of the states. Obviously, the shifts in coal production would have other consequences, including lost income from both coal sales and coal-induced employment, loss of state and local income and property taxes, and higher budgets for unemployment compensation and other social welfare programs.

I want to reiterate that the assumptions we have used result in cost estimates that are more conservative than those that may actually occur. Conversely, our employment impact projections may be diminished to the extent that utilities responded to the SO_2 emission reductions by retrofitting FGD units.

I would be happy to answer any questions that you may have.

***

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WASHINGTON, D.C. 20036
TELEPHONE (202) 659-8101

CHRIS FARRAND
VICE PRESIDENT
GOVERNMENT RELATIONS

June 3, 1982

Mr. Curtis A. Moore
Associate Counsel
Committee on Environment
and Public Works
United States Senate
4204 Dirksen Senate Office Bldg.
Washington, D. C. 20510

Dear Curtis:

Enclosed are the responses to the written questions provided at the June 2 staff meeting on the economic effects of various acid rain programs.

Sincerely,

Chris Farrand /dl

Chris Farrand

Enclosure

CF/dl

June 2, 1982

PEABODY COAL COMPANY RESPONSES TO QUESTIONS PROVIDED BY THE SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS ON THE ECONOMIC EFFECTS OF VARIOUS ACID RAIN PROGRAMS

I. How were your emission reductions calculated? Please include in answer:

A. Method (e.g., ARMS region least cost, S. 1706, etc.) and baseline year.

RESPONSE: In accordance with the provisions of S. 1706, Peabody determined the total emissions in the Acid Precipitation Region from sources emitting at a rate which exceeds 1.2 lbs. of SO_2 per million BTUs, the total emissions in each state from such sources, and then applied the ratio of the two emission levels as a percentage against the 10-million-ton reduction specified in the bill. This provides the amount of reduction in SO_2 emissions each state would be required to achieve annually by 1990, and thus the new allowable SO_2 emissions for 1990 for each of the affected states. From this amount, we were able to calculate the quantity of coal which was "unacceptable" and which must be replaced by lower sulfur or "acceptable" coal or oil to achieve the required reductions through fuel blending.

Using 1980 data on the delivered costs of both higher sulfur and lower sulfur fuels in each state, we were able to determine the unit cost differential. This cost differential was then multiplied by the number of tons of substitute coal required, measured on a BTU-equivalent basis. The result is a dollar figure for each of the states affected by the legislation.

1. Are new sources offset from existing?

RESPONSE: No. We did not account for new growth and assumed a 10-million-ton reduction from current levels only.

2. NO_x for SO_2 trades allowed? Why/Why not?

RESPONSE: We did not account for NO_x reductions because (a) we had no data on current NO_x emissions, and (b) our analysis did not include technology responses. (Switching fuels has no effect on reducing NO_x emissions.)

3. Industrial emissions trades allowed? New source industrial emissions offset?

RESPONSE: The analysis assumes all reductions would come from utility sources; no industrial emission reductions were contemplated.

4. Is an absolute emissions ceiling imposed? At what level?

RESPONSE: No absolute emission ceiling was imposed. In fact, our analysis assumes intrastate trading to achieve each state's quota of emission reductions.

B. Provide state-by-state reduction estimates.

RESPONSE: State-by-state reduction estimates are attached.

C. How much of this reduction did you assume would be done by utilities? (Provide 1990 emissions estimates with and without reduction strategy.)

RESPONSE: We assume 100 percent of the reduction would come from utility sources.

D. How much of the SO_2 emissions in each of the studied states comes from utilities?

RESPONSE: See response to Question I.C.

1. Were other sources of reduction considered in your plan? Why/Why not?

RESPONSE: At the time we conducted the analysis, we had data only for utility sources. However, as the ICF and other studies show, the opportunity for reductions from industrial sources is quite limited.

E. Did you do any calculations on NO_x emissions? Why/Why not? Do you have any?

RESPONSE: No calculations were made for NO_x emissions. We do not have adequate data to make such calculations.

II. How did you choose your reduction alternatives? Please justify fully.

RESPONSE: Peabody's assumption about coal switching is based on our experience in the market and our knowledge of the technological, political and economic constraints to the retrofit of scrubbers on existing powerplants. When we began our analysis, we thought that the entire 10-million-ton reduction could be met by coal switching. However, in our state-by-state approach, we found that the requirement for coal substitutions to be much larger than anticipated. In reality, it is unlikely that the entire 10-million-ton reduction requirement could be met by coal switching alone.

A. Percentage of each alternative chosen in terms of tons of SO_2 or NO_x removed.

RESPONSE: Not pertinent to Peabody's analysis.

B. Were NO_x reductions considered? Why/Why not?

RESPONSE: See answers to Questions I.A.2. and I.E. above.

C. Were intersystem or other trading schemes considered Why/Why not?

RESPONSE: We assumed intrastate trading which would include trading between systems within a state. Our analysis considers the average allowable emissions on a state-wide basis. The required reduction is achieved by utilizing an average blend of low and high-sulfur coals, allowing free substitution within a state.

III. What is the total average cost per ton of SO_2 or NO_x for each alternative employed in your study? Please explain fully your accounting method (annualized, levelized, present value, etc.) and how you calculated it.

RESPONSE: Under Peabody's analysis, the total average cost per ton of SO_2 removed is $320 in 1980 dollars or $400 in current dollars. These are first-year differential costs; in effect they are annualized, at least for the remaining useful life of the affected plants. No present value calculations were made.

A. Scrubber costs: capital costs (per KW), O and M costs, capacity and energy penalties. (If possible, use 500 MW unit for comparison.)

RESPONSE: Not pertinent to Peabody's analysis.

B. New Plant costs: capital costs (per KW), O and M costs, percentage of these costs which are attributed to the bill as opposed to eventual turnover in generating capacity.

RESPONSE: Not pertinent to Peabody's analysis.

C. Other Capital Costs: e.g., costs for boiler retrofit or ESP.

RESPONSE: Not pertinent to Peabody's analysis.

D. Fuel Switching: include capital costs (e.g., boiler retrofit or particulate control); fuel price differential (use 6 lb/mmBtu coal for comparison).

RESPONSE: Under our fuel-switching scenario, we did not include capital costs for boiler retrofit, particulate control or additional coal blending equipment. However, the average fuel price differential was approximately $10.60 per ton delivered based on 1980 data for various quality coals. Where there was no data for low-sulfur "acceptable" coal within a state, data for an adjacent state used without any additional transportation costs imputed. Our October testimony outlines our method of deriving these costs on a state-by-state basis.

E. Capitalization: depreciation and interest rates assumed (list these separately).

RESPONSE: Not pertinent to Peabody's analysis.

F. Total costs of removal per state studied (note above request on explaining figures).

RESPONSE: See response to Question I.B.

1. Are costs to reach SIP compliance included?

RESPONSE: The analysis measures reductions below 1980 emission levels without regard to whether they are achieved for SIP compliance reasons or because of S. 1706.

2. If you used an emissions ceiling, how much less would be the cost without the emissions ceiling?

RESPONSE: Not pertinent to Peabody's analysis; no emission ceiling was used.

IV. How were rate increases calculated? (as before, please explain calculations fully.)

RESPONSE: Peabody assumed direct pass-through of the differential coal costs. We believe that the pass-through would be accomplished by a fuel cost adjustment on the consumer's monthly bill. Since no capital costs were derived under our analysis, no other calculation for rate increases was made.

A. Are the increases strictly from the bill?

RESPONSE: Yes.

B. What is the percentage increase in rates in 1990 due to the reduction program alone, expressed as a percent of 1980 rates, and also as a percent of projected 1990 rates?

RESPONSE: Not pertinent to Peabody's analysis.

V. Please bring any sensitivity analyses or other runs that you have prepared.

RESPONSE: Peabody did not conduct any sensitivity analyses. However, it should be noted that our study did not account for increases in low-sulfur coal prices due to a sudden surge in demand. If such prices increase, it would have a magnified effect on the cost of S. 1706. For example, a 10 percent increase in low-sulfur coal prices would result in a 43 percent increase in the fuel cost differential, or a 43 percent increase in the cost of S. 1706 under a fuel-switching scenario.

VI. Please note the enclosed list of assumptions and methodology from a recent report by the Congressional Budget Office, The Clean Air Act, the Electric Utilities, and the Coal Market. Please indicate which of your assumptions, if any, differed from those of CBO and state why. Please do the same as to methodology.

RESPONSE: Since Peabody used empirical data from 1980 to arrive at a fuel cost differential, we did not make assumptions about capital costs, GNP growth, world oil prices, etc. Hence, the assumptions used in the CBO report do not have a bearing on Peabody's analysis. The assumptions we used are listed in our prepared statement of June 2, which we attach.

OCTOBER 1981
PAGE ONE OF TWO

ATTACHMENT A

PROJECTED 1980 COAL COSTS FOR S. 1706 1/

STATE	TOTAL SO_2 EMISSIONS GREATER THAN 1.2 LBS./MM BTU TONS X000 2/			REQUIRED REDUCTION IN TOTAL SO_2 EMISSIONS TONS X000			COAL GREATER THAN 1.2 LBS./MM BTU DISPLACED TONS X000	INCREASED COAL COST DUE TO DISPLACEMENT $ X000
	COAL	OIL	TOTAL	COAL	OIL	TOTAL		
Alabama	314.7	-	314.7	297.0	-	297.0	15,300.4	$289,353.2
Arkansas	-	3.1	3.1	-	2.9	2.9	-	-
Connecticut	-	-	-	-		-	-	-
Delaware	15.5	0.2	15.7	14.6	0.2	14.8	755.7	14,951.9
Florida	236.3	93.6	329.8	223.0	88.3	311.3	6,976.1	13,342.0
Georgia	444.6	3.2	447.8	419.7	3.0	422.7	17,762.0	215,890.7
Illinois	811.2	-	811.2	765.7	-	765.7	16,944.4	232,862.6
Indiana	1,354.9	-	1,354.9	1,278.9	-	1,278.9	29,300.9	454,858.3
Iowa	100.0	-	100.0	94.4	-	94.4	2,074.0	13,164.0
Kentucky	845.0	-	845.0	797.6	-	797.6	22,477.7	224,701.7
Louisiana	-	0.5	0.5	-	0.5	0.5	-	-
Maine	-	2.4	2.4	-	2.3	2.3	-	-
Maryland	97.9	7.9	105.8	92.4	7.5	99.9	5,534.9	24,809.1
Massachusetts	3.8	93.2	97.0	3.6	88.0	91.6	493.3	4,590.2
Michigan	227.8	-	227.8	215.0	-	215.0	5,255.1	28,498.8
Minnesota	89.6	0.7	90.3	84.6	0.7	85.2	8,410.8	115,224.2
Mississippi	62.9	25.1	88.0	59.4	23.7	83.0	2,004.8	41,088.7
Missouri	917.9	0.5	918.4	866.4	0.5	866.9	16,761.3	261,161.6

PAGE TWO OF TWO

STATE	TOTAL SO_2 EMISSIONS GREATER THAN 1.2 LBS./MM BTU TONS X000 2/			REQUIRED REDUCTION IN TOTAL SO_2 EMISSIONS TONS X000			COAL GREATER THAN 1.2 LBS./MM BTU DISPLACED TONS X000	INCREASED COAL COST DUE TO DISPLACEMENT $ X000
	COAL	OIL	TOTAL	COAL	OIL	TOTAL		
New Hampshire	33.9	9.9	43.8	32.0	9.3	41.3	955.4	17,820.5
New Jersey	40.0	1.9	41.9	37.7	1.8	39.6	2,103.4	23,617.9
New York	128.5	73.2	201.7	121.3	69.1	190.4	5,681.4	115,054.4
North Carolina	82.4	-	82.4	77.8	-	77.8	12,479.7	171,890.9
Ohio	1,704.8	0.2	1,705.0	1,609.2	0.2	1,609.4	41,616.8	254,599.3
Pennsylvania	1,082.0	-	1,082.0	1,021.3	-	1,021.3	39,082.4	352,563.2
South Carolina	96.2	6.4	102.6	90.8	6.0	96.8	6,198.5	86,908.7
Tennessee	633.2	-	633.2	597.7	-	597.7	20,640.5	71,537.0
Vermont	-	-	-	-	-	-	-	-
Virginia	8.9	9.0	17.9	8.4	8.5	16.9	2,107.0	(3,414.2)
West Virginia	594.7	-	594.7	561.4	-	561.4	18,361.7	170,762.3
Wisconsin	337.0	0.1	337.1	318.1	0.1	318.2	7,788.3	64,856.8
Wash., D. C.	-	-	-	-	-	-	-	-
TOTALS	10,263.6	335.8	10,594.8	9,688.0	312.6	10,000.0	307,066.5	$3,260,693.8

1/ Cost and Quality of Fuels for Electric Utility Plants, 1980 Annual, U.S. Department of Energy, DOE/EIA-0191(80), June 1981

2/ Emissions calculated from fossil fuel receipts to steam-electric units 25 MW or greater, 1980. Emission levels do not reflect the use of FGD equipment. Forty-six (46) scrubbers are currently in place in plants burning 7.8% of coal. At design efficiencies, these scrubbers would reduce emissions by approximately 6.5%.

OCTOBER 1981

APPENDIX

Incremental costs are based on differentials between weighted average 1980 delivered prices of acceptable coal and non-acceptable coal within each state multiplied by the number of tons to be displaced. For purposes of this study, acceptable coal is defined as coal of appropriate BTU and sulfur content which, when combusted, has the potential to produce SO_2 emissions of 1.2 lbs. per million BTUs or less. If no acceptable coal was delivered to the state in 1980, acceptable coal prices were based on weighted average 1980 delivered prices to an adjacent or nearby state as explained below. All prices are based on the weighted average of all coal deliveries of comparable coal quality to the state in the compliance or non-compliance category.

Alabama - Compliance coal prices were based on weighted average 1980 delivered prices for compliance coal to Mississippi from Colorado and Utah, and to Florida from Virginia and West Virginia.

Delaware - Based on deliveries to Delaware from West Virginia, and to New Jersey from Kentucky.

Georgia - Based on deliveries to Florida from Virginia and West Virginia.

Maryland - Based on deliveries to Delaware from West Virginia, and to Virginia from Kentucky, Virginia, and West Virginia.

Massachusetts - Based on deliveries to New Jersey from Georgia, Kentucky and West Virginia.

Minnesota - Based on an arithmetic average of deliveries to Iowa from Colorado and Wyoming.

North Carolina - Based on deliveries to Kentucky from Virginia and West Virginia.

New Hampshire - Based on deliveries to New Jersey from Georgia, Kentucky, and West Virginia.

New York - Based on deliveries to New Jersey from Georgia, Kentucky, and West Virginia.

Pennsylvania - Based on deliveries to Ohio from Pennsylvania, Tennessee, Virginia, and West Virginia.

South Carolina - Based on deliveries to Kentucky from Virginia and West Virginia, and to Florida from Virginia and West Virginia.

Tennessee - Based on deliveries to Ohio from Pennsylvania, Tennessee, Virginia and West Virginia.

Wisconsin - Based on an arithmetic average of deliveries to Iowa from Colorado and Wyoming.

ECONOMIC AND EMPLOYMENT IMPACTS
OF PROPOSED
ACID RAIN LEGISLATION

UNITED MINE WORKERS OF AMERICA

JUNE 2, 1982

The UMWA represents over 250,000 working, retired and unemployed coal miners throughout the United States and Canada. While our membership is heaviest in coal mining communities east of the Mississippi River, we represent underground and surface miners throughout the Western states, with members in Arizona, New Mexico, North Dakota, Colorado, Wyoming, Montana, and Utah.

Our membership has a strong interest in the current Congressional Reauthorization of the Clean Air Act both as workers and citizens. As the nation's largest energy-producing Union, we are concerned that our pollution control strategies recognize the need for balanced energy development; the jobs of thousands of our members and the economies of the communities in which they live are affected by environmental decisions. As citizens, of both Canada (where we represent thousands of coal miners in Nova Scotia and British Columbia) and the United States, we are concerned that business interests not override the clearly established need for clean and healthful air. We appreciate the opportunity to present our analysis of the employment and economic impacts of the current legislative proposals regarding acid rain.

The UMWA has reviewed S.1706, a bill sponsored by Senator Mitchell and several other United States Senators, including six members of the Committee on Environment and Public Works, within whose jurisdiction the bill lies. S.1706 is designed to reduce the effects of acid deposition by requiring a significant reduction in sulfur dioxide emissions in the states along and east of the Mississippi River. In the course of reviewing this proposed legislation, we have also examined the study conducted by the Peabody Coal Company assessing this bill's effect on current coal production in twelve eastern and midwestern states.

Based on the analysis, the UMWA has measured the impacts of the reported production losses on jobs. We have also measured, in dollar terms, the effect of S.1706 on the economies of those same 12 producing states. The results of our study are summarized in Attachment A.

In this study, the UMWA adopted the projected coal production losses that Peabody estimates will occur if S.1706 becomes law. The Peabody study assumed that utilities would switch to low sulfur coal, rather than retrofit their existing power plants with scrubbers, in order to meet the emission reductions required under the bill. Given fuel adjustment clause "pass-through" provisions and utility capital formation problems, this presumption is a realistic expectation of how utilities would respond to this acid rain mitigation plan.

Utilities have several options in responding to S.1706; they can choose early retirement of existing plants, utilize scrubber technology, engage in coal blending or fuel switching. The latter two options will result in job losses. It should be noted that partial loss of a coal supply contract can result in the closing of a mine. Since there is not a one-to-one relationship between production losses and job losses, the UMWA analysis more accurately anticipates the impact of S.1706 in accounting for partial production losses. Even assuming that 25 percent and 50 percent of the projected loss of high sulfur coal would not occur--instead of fuel switching, scrubbers would be installed at some existing plants--the economic impact of S.1706 would still be significant, $4.97 billion and $3.32 billion respectively.

In the United States, there are more than 29,000 UMWA members who are presently unemployed, with the greatest percentage of that unemployment coming from the high sulfur coal fields of the midwest--Indiana, Illinois, Ohio and Western Kentucky--and in northern Appalachia. Many of these same states--Indiana, Ohio and Illinois--have among the highest unemployment rates in the nation. Our analysis indicates that more than 15,000 coal mining industry jobs would be lost in Illinois alone if S.1706 was passed. Similarly 5,400 jobs would be eliminated in Indiana, better than 12,300 eliminated in Ohio, and more than 11,500 persons would become unemployed in Kentucky if the bill becomes law.

A second acid rain control program has been proposed in the Senate. Senator Moynihan of New York has introduced S.1709, which is similar to the previously discussed Mitchell bill in that it specifies the same 31 state region as the control area. There are other similarities such as the flexibility allowed to the states in implementing those reductions. However, the Moynihan bill differs from the Mitchell bill by not specifying the amount of sulfur dioxide emission reductions required. Moreover, under Moynihan only about 60 large power plants located in 16 of the 31 states included in the acid rain mitigation region, would be required to reduce emissions. Most of those power plants are located in Ohio, Kentucky, Indiana, Illinois, Tennessee, Missouri, Pennsylvania, and Michigan, all traditional market areas for eastern and midwestern coal.

At the request of the Senate Committee on Environment and Public Works and the House Energy and Commerce Committee--the two committees that are reviewing the Clean Air Act--the Congressional Office of Technology Assessment (OTA) compared the emission reductions required under both bills. The Mitchell bill would require a 44.8% reduction in SO_2 emissions from current levels, while the Moynihan bill would require a 36.4% reduction. Those percentages reflect the overall emissions reduction in the 31 state region. The OTA analysis, which was presented as testimony in November, 1981 before the Senate Environment and Public Works Committee, also compared the percent of sulfur dioxide emission reductions on a state by state basis. The UMWA has forecasted coal production losses in 11 eastern and midwestern states based on a factor derived from the OTA analysis.

According to the UMWA forecast found as Attachment B, S.1709 would have the same devastating impact on coal miner jobs and the economic viability of the areas in which we live, as does S.1706. The employment and economic impact of S.1709 is greater in Kentucky and Tennessee than those felt from S.1706, while the effects are marginally less in the other states studied. And, as can be seen readily, the total impact on the coal mining industry in the midwest and eastern coal producing states is extraordinary.

Many of these states analyzed already have crippling unemployment rates, particularly in their basic industry sectors. Passage of either the Mitchell or the Moynihan bill would aggravate that situation dramatically.

Congress had several goals in mind when the Clean Air Act was reauthorized in 1977. In the pursuit of cleaner air, Congress intended that all of our nation's energy resources be developed, that employment opportunities be enhanced and that the various regions of the country be given equal opportunities to compete for economic development. Adoption of any acid rain strategy that disrupts traditional coal markets, brings about wholesale unemployment and favors one part of the nation over another is wholly inconsistent with these goals. The UMWA opposes any such legislation.

Attachment A

November 2, 1981

EMPLOYMENT AND ECONOMIC IMPACTS OF S.1706 IN COAL PRODUCING STATES

STATES	TOTAL TONS OF COAL DISPLACED (X10^3) UNDER S.1706[1]	AVERAGE ANNUAL TONNAGE OUTPUT PER COAL MINING INDUSTRY EMPLOYEE[2]	COAL MINING INDUSTRY EMPLOYEE JOB LOSSES	TOTAL ANNUAL COAL MINING INDUSTRY EMPLOYEE ECONOMIC LOSSES (X10^6)[3]	INDIRECT ECONOMIC LOSSES MULTIPLIER[4]	TOTAL ANNUAL INDIRECT ECONOMIC LOSSES (X10^6)	TOTAL ANNUAL ECONOMIC LOSSES (X10^6)[5]
Alabama	12,289.4	2,422	5,074	$130.4	2.22	$ 289.6	$420.0
Illinois	45,260.9	2,912	15,543	398.5	2.25	896.7	1,295.2
Indiana	24,677.8	4,570	5,400	139.3	1.40	195.0	334.3
Iowa	317.0	4,059	78	2.0	2.64	5.2	7.2
Kentucky	34,632.8	2,992	11,575	297.2	1.96	582.6	879.8
Maryland	1,067.2	3,029	352	9.0	4.70	42.0	50.9
Missouri	3,024.3	4,069	743	19.1	2.77	52.8	72.0
Ohio	31,382.0	2,548	12,316	312.9	1.51	472.4	785.3
Pennsylvania	46,289.4	2,583	17,921	462.1	1.79	827.1	1,289.2
Tennessee	6,492.6	2,551	2,545	65.9	2.21	145.7	211.6
Virginia	6,768.6	2,261	2,994	80.0	3.58	279.2	357.2
W. Virginia	31,259.8	2,122	14,731	379.8	1.45	550.8	930.6
TOTAL	243,461.8		89,272	$2,294.1		$4,339.0	$6,633.1

FOOTNOTES TO ATTACHMENT A

1. Peabody Coal Company testimony on S.1706 before the United States Senate Committee on Environment and Public Works, October 29, 1981.

2. State average annual tonnage output per coal mining industry employee derived from the U.S. Department of of Labor, Mine Safety and Health Administration's (MSHA) currently unpublished report on injury experience in coal mining, 1980. MSHA utilizes information provided by coal operators on a mandatory basis as required under the Federal Mine Safety and Health Act of 1977. All mine, plant and office employees' hours are assumed, as is an eight hour day and a 234 day work year. Figures are slightly understated since unionized surface mine production employees work 7.25 hours per day. Because all coal mining industry employees are included in this factor, it differs from more traditional "miner productivity" statistics.

3. United States Department of Labor, Bureau of Labor Statistics, Employment and Earnings, October, 1981 and National Survey of Professional, Administrative, Technical, and Clerical Pay, March 1981. Average annual earnings for coal mining industry employees is weighted between production and office workers.

4. These economic losses multipliers reflect the average relationship in each coal producing state in the proposed Acid Rain Mitigation Region, between basic and non-basic income. Mining, agriculture and manufacturing income comprise the basic sector; total community earnings less basic sector income constitute the non-basic sector. Income information and total community earnings are taken from U.S. Department of Commerce, Bureau of Economic Analysis, Volumes 3 (Mideast), 4 (Great Lake), 5 (Plains) and 6 (Southeast), Local Area Personal Income, 1974-79, June 1981. Tables 5 "Personal Income for States, Counties, and Independent Cities of the Region, 1974-79" were used, with multipliers computed for the year 1979.

   Higher multipliers reflect the greater percentage of support, non-basic services in the economies of those states. In those cases, basic industry supports a greater volume of services. Lower multipliers tend to reflect more industrialized-dependent economies.

   This methodology for determining the average effect on non-basic income due to a change in income in the basic sector is equivalent to the methodology used by the Coal Extraction and Utilization Research Center at

Southern Illinois University, Carbondale, Illinois in The Economic Impact of Western Coal in Illinois, June 22, 1979. The multiplier computed for Illinois coal field areas measures the average effect base income has on personal income and are comparable, for the last year included in the SIU study (1974), to those derived from the twelve states in this study.

The SIU analysis presumes that the non-base sector is the service sector and is dependent on the base sector. It should be noted that the impact on the base sector is immediate, whereas the impact on the non-base sector will occur over time.

5. Totals may not add due to rounding.

ATTACHMENT B

EMPLOYMENT AND ECONOMIC IMPACTS OF S.1709 IN COAL PRODUCING STATES

STATES	TOTAL TONS OF COAL DISPLACED (x10^3) UNDER S. 1709 1/	AVERAGE ANNUAL TONNAGE OUTPUT PER COAL MINING INDUSTRY EMPLOYEE 2/	COAL MINING INDUSTRY EMPLOYEE JOB LOSSES	TOTAL ANNUAL COAL MINING INDUSTRY EMPLOYEE ECONOMIC LOSSES (x10^6) 3/	INDIRECT ECONOMIC LOSSES MULTIPLIER 4/	TOTAL ANNUAL INDIRECT ECONOMIC LOSSES (x10^6)	TOTAL ANNUAL ECONOMIC LOSSES (x10^6) 5/
Alabama	8,782.4	2,422	3,626	$ 93.2	2.22	$ 206.9	$ 300.1
Illinois	36,785.8	2,312	12,632	323.9	2.25	728.7	1,052.6
Indiana	24,333.3	4,570	5,325	137.4	1.40	192.3	329.7
Iowa	50.0	4,059	12	.3	2.64	.8	1.1
Kentucky	39,037.6	2,992	13,047	335.0	1.96	656.7	991.7
Missouri	2,487.4	4,069	611	15.7	2.77	43.4	59.1
Ohio	28,884.5	2,548	11,336	288.0	1.51	434.8	722.8
Pennsylvania	40,803.3	2,583	15,797	407.3	1.79	729.1	1,136.4
Tennessee	7,313.3	2,551	2,867	74.3	2.21	164.1	238.4
Virginia	6,768.6	2,261	2,994	80.0	3.58	279.2	357.2
W. Virginia	29,908.3	2,122	14,094	363.4	1.45	526.9	890.4
TOTAL:	225,154.5		82,341	$2,116.4		$3,963.1	$6,079.5

FOOTNOTES TO ATTACHMENT B

1. Tons of coal displaced was determined using a factor derived from the office of Technology Assessment testimony on S.1706 and S.1709 before the United States Senate Committee on Environment and Public Works, October 29, 1981, Table 4 "Comparison Between Mitchell and Moynihan Bills" and Peabody Coal Company testimony on S.1706 before the United States Senate Committee on Environment and Public Works, October 29, 1981. This analysis assumes that if the required reductions in current sulfur dioxide emissions, calculated by OTA, displaces the amount of coal predicted by Peabody under S.1706, then the required reduction in emissions under S.1709 will displace an amount of coal production equal to a factor of the two percentages times the forecasted coal displaced under S.1706. For example, S.1706 will require Alabama to reduce emissions 41.0 percent below current levels; similarly S.1709 will require 29.3 percent reduction in emissions. Peabody has determined that S.1706 will displace 12,289,400 tons of coal production. Thus the coal production impact of S.1709 using this analysis will be (29.3/41.0) 12,289,400 = 8,782,425.

2. State average annual tonnage output per coal mining industry employee derived from the U.S. Department of Labor, Mine Safety and Health Administration (MSHA), Injury Experience in Coal Mining, 1980, Table 6 "Injury Experience by Degree, Worktime, and Production for Work Location and State at all Coal Operations in the United States, 1980". MSHA utilizes information provided by coal operators on a mandatory basis as required under the Federal Mine Safety and Health Act of 1977. All mine, plant and office employees' hours are assumed, as is an eight hour day and a 234 day work year. Figures are slightly understated since unionized surface mine production employees work 7.25 hours per day. Because all coal mining industry employees are included in this factor, it differs from more traditional "miner productivity" statistics.

3. United States Department of Labor, Bureau of Labor Statistics, Employment and Earnings, October, 1981 and National Survey of Professional, Administrative, Technical, and Clerical Pay, March 1981. Average annual earnings for coal mining industry employees is weighted between production and office workers.

4. These economic losses multipliers reflect the average relationship in each coal producing state in the proposed Acid Rain Mitigation Region, between basic and non-basic income. Mining, agriculture and manufacturing income comprise the basic sector; total community earnings less basic sector income constitute the non-basic sector. Income information and total community earnings are taken from U.S. Department of Commerce, Bureau of Economic Analysis,

Volumes 3 (Mideast), 4 (Great Lakes), 5 (Plains) and 6 (Southeast), Local Area Personal Income, 1974-79, June 1981. Tables 5 "Personal Income for States, Counties, and Independent Cities of the Region, 1974-79" were used, with multipliers computed for the year 1979.

Higher multipliers reflect the greater percentage of support, non-basic services in the economies of those states. In those cases, basic industry supports a greater volume of services. Lower multipliers tend to reflect more industrialized-dependent economies.

This methodology for determining the average effect on non-basic income due to a change in income in the basic sector is equivalent to the methodology used by the Coal Extraction and Utilization Research Center at Southern Illinois University, Carbondale, Illinois in The Economic Impact of Western Coal in Illinois, June 22, 1979. The multiplier computed for Illinois coal field areas measures the average effect base income has on personal income and are comparable, for the last year included in the SIU study (1974), to those derived for the states in this study.

The SIU analysis presumes that the non-base sector is the service sector and is dependent on the base sector. It should be noted that the impact on the base sector is immediate, whereas the impact on the non-basic sector will occur over time.

5. Totals may not add due rounding.

DOE F 1325.8
(7-79)

U.S. DEPARTMENT OF ENERGY

memorandum

DATE: June 9, 1982

REPLY TO ATTN OF: PE-36

SUBJECT: Q's and A's on Acid Rain for Senate Environment and Public Affairs Committee

TO: Fred Tathwell, Congressional Affairs

THRU: Richard Williamson WJP [illegible] for

As requested, attached are the answers to the questions provided by staffers of the Senate Committee on DOE's Acid Rain Cost Analysis. Question V requires no answer.

Jack Siegel

Attachment

ANSWERS TO QUESTIONS ON DOE'S SO_2 CONTROL COSTS STUDY

Question I:

How were your emission reductions calculated? Please include in answer:

A. Method (e.g., ARMS region least cost, S.1706, etc.) and baseline year.

   1. Are new sources offset from existing?

   2. NO_x for SO_2 trades allowed? Why/Why not?

   3. Industrial emissions trades allowed? New source industrial emissions offset?

   4. Is an absolute emissions ceiling imposed? At what level?

B. Provide state-by-state reduction estimates.

C. How much of this reduction did you assume would be done by utilities? (Provide 1990 emissions estimates with and without reduction strategy.)

D. How much of the SO_2 emissions in each of the studied states come from utilities?

   1. Were other sources of reduction considered in your plan? Why/Why not?

E. Did you do any calculations on NO_x emissions? Why/Why not? Do you have any?

Answer I:

Emissions weren't calculated, rather a minimum cost range was calculated given emission reductions.

The study first uses a straight-forward technique to calculate the range of costs that should be anticipated if each of three control methods is used to obtain a one million ton per year reduction. The control methods include coal cleaning, coal switching and flue gas scrubbing. Input data for this portion of the study consists of the range of capital and operating costs associated with coal switching and flue gas desulfurization and the additional costs to a utility of purchasing pre-cleaned coal. These costs are combined with the estimated effectiveness of each of the above measures on coals with sulfur contents of 3 percent or greater and of 2 percent or greater. The lack of site-specific details is recognized by using cost ranges as opposed to single point estimates as input to the calculations. The key assumption in this portion of the study is that each of the control methods reviewed is most cost-effective (on a dollar per ton of SO_2 removed basis) when applied to higher sulfur coals. This assumption, however, has been verified in a large number of studies on sulfur dioxide control costs.

The second portion of the study compares the previous calculations with results obtained from three recent contractor-performed studies. After the contractor studies are placed on a consistent calculational basis (i.e., consistent financial parameters), it is found that they are in reasonable agreement with one another and with the above-mentioned DOE analysis. Significant assumptions, input variables, and calculations are included in the Appendix to the Report.

The following responds to questions IA through IE:

A. 1. Controls are assumed for existing high sulfur coal users only.

2. Costs for SO_2 control are the only ones considered. NO_x analysis was beyond the scope of the DOE study.

3. The DOE study dealt exclusively with utilities.

4. No ceilings were imposed; costs per million tons of SO_2 reduced is the principal estimate made.

B. 1. The DOE study looks at the national level although the ranges used could incorporate state variations. It should be noted, most of the impact of a control program concentrating on high sulfur coal users will primarily effect ten midwestern states (see pages 12-15 of the report).

C. All reductions imposed on utilities.

D. Same as C.

E. No. Beyond the scope of our analysis.

Question II.

How did you choose your reduction alternatives? Please justify fully. Also include:

A. Percentage of each alternative chosen in terms of tons of SO_2 or NO_x removed.

B. Were NO_x reductions considered? Why/Why not?

C. Were intersystem or other trading schemes considered? Why/Why not?

Answer II:

No reduction alternatives were chosen. Rather the costs of between a 0 and 10 million ton reduction program were estimated.

A. All SO_2

B. No; NO_x was beyond the scope of DOE's study.

C. Least cost approach inherent in the analysis. However, some other strategies are included in the comparison of DOE estimates with contractor estimates (see Appendix, page 20).

Question III.

What is the total average cost per ton of SO_2 or NO_x for each alternative employed in your study? Please explain fully your accounting method (annualized, levelized, present value, etc.) and how you calculated it. Please include:

A. Scrubber costs: capital costs (per KW, O and M costs, capacity and energy penalities. (If possible, use 500 MW unit for comparison.)

B. New Plant costs: capital costs (per KW), O and M costs, percentage of these costs which are attributed to the bill as opposed to eventual turnover in generating capacity.

C. Other Capital Costs: e.g., costs for boiler retrofit or ESP.

D. Fuel switching: include capital costs (e.g., boiler retrofit or particulate control); fuel price differential (use 6 lb/mmBtu coal for comparison).

E. Capitalization: depreciation and interest rates assumed (list these separately).

F. Total costs of removal per state studied (note above request on explaining figures).

1. Are costs to reach SIP compliance included?

2. If you used an emissions ceiling, how much less would be the cost without the emissions ceiling?

Answer III:

For the range of SO_2 reductions analyzed (1 to 10 million tons per year), DOE estimated the average cost per million tons of SO_2 reduced to be approximately $200 to $450 in 1980 dollars. Beyond 10 million tons reduction costs are likely to be $600 to $800 per ton removed. Ranges of costs are also provided in the following terms:

- capital costs
- O&M costs
- annualized costs
- present value
- 30-year expenditures in 1980$.
- 30-year expenditures in nominal $.

The methodology used to derive DOE's estimates are described fully in the Appendix of the report.

It should be noted that these costs should be considered minimum costs since:

- Major cost elements such as transportation costs and the price response due to disruption of the coal market may be seriously underestimated.

- Economically efficient regulations are unlikely to be achieved in practice.

A. Scrubber costs used are:

- capital costs: $140 to $250 per kw capacity
- O&M costs: 3 to 6 mills per kwh

B. New plant costs were not considered; controls were imposed only on existing plants.

C. The only other capital costs considered were for the upgrading equipment needed for coal switching. These costs were assumed to be $21 to $50 per kw capacity.

D. The fuel price differentials assumed were:

- for coal switching: $6 to $12 per ton for switching from coals greater than 3% in sulfur to a 1% sulfur coal; $4 to $10 per ton for switching from coals greater than 2% in sulfur content to a 1% sulfur coal.
- for coal cleaning, $3 to $5 per ton for 20% removal.

E. Assumed a 5% discount rate (real) with a 30-year investment lifetime to calculate annualized and present value costs.

F. It was beyond the scope of DOE's study to analyze the costs to individual states.

Question IV:

How were rate increases calculated? (as before please explain calculations fully.)

A. Are the increases strictly from the bill?

B. What is the percentage increase in rates in 1990 due to the reduction program alone, expressed as a percent of 1980 rates, and also as a percent of projected 1990 rates?

Answer IV:

The methodology for calculating rate increases is described fully on pages 14 and 16 in the appendix to the DOE study.

A. Yes.

B. The percentage increase in rates over current electricity rates varies from 4 to 26% in the most highly impacted 10 states. It was beyond the scope of the DOE analysis to analyze the effect the control program would have in 1990. It is possible that the rate increases will be even higher if low sulfur coal prices escalate rapidly because of the large increase in its demand as a result of acid rain control requirements.

Question V:

Please bring any sensitivity analyses or other runs that you have prepared.

Answer V:

The ranges in the results of the DOE analysis represent sensitivities to a number of factors (costs, control methods, quantities controlled).

Question VI:

Please note the enclosed list of assumptions and methodology from a recent report by the Congressional Budget Office, The Clean Air Act, the Electric Utilities, and the Coal Market. Please indicate which of your assumptions, if any, differed from those of CBO and state why. Please do the same as to methodology.

Answer VI:

DOE assumed a 5% real discount rate over 30 years of investment lifetime; CBO estimated 4.27%.

National Clean Air Coalition
Responses to Senate Staff Acid Rain Inquiries

Question:

I. How were your emission reductions calculated? Please include in answer:

A. Method (e.g., ARMS region least cost, S. 1706, etc.) and baseline year.

1. Are new sources offset from existing?

2. NO_x for SO_2 trades allowed? Why/Why not?

3. Industrial emissions trades allowed? New source industrial emissions offset?

4. Is an absolute emissions ceiling imposed? At what level?

Response:

I. A. Our analysis examined the costs of reducing SO_2 emissions in the 31 state acid rain mitigation region by 10 million tons from forecasted emissions in the years 1990 and 2000. Since we analyzed a reduction in forecasted emissions the analysis places no limits on increases in emissions from either existing or new sources due to increased fuel combustion. Such emission increases are not required to be offset. In addition, emission reductions from existing sources required to comply with state implementation plans are not credited against the 10 million ton reduction requirement.

Our analysis did not permit SO_2 reduction obligations to be traded for NO_x emission reductions. We support this as a policy approach. However, we lacked the funds to have this option modelled.

Our analysis assumed all SO_2 reductions came from the utility sector. We support the policy option of allowing industrial SO_2 emission reductions to be credited toward the 10 million ton reduction total. However, we lacked the funds to model this option.

No absolute emissions ceiling was imposed in our analysis.

Question:

I. B. Provide state-by-state reduction estimates.

Response:

I. B. State-by-state reduction estimates are listed in Tables 7-9 (pages 23-24) of the ICF Report dated November 14, 1981 for the National Wildlife Federation and the National Clean Air Coalition entitled "Cost and Coal Production Effects of Reducing Electric Utility Sulfur Dioxide Emissions." (NWF/NCAC Report.)

Question:

I. C. How much of this reduction did you assume would be done by utilities? (Provide 1990 emissions estimates with and without reduction strategy.)

Response:

I. C. As stated above our analysis assumed the entire SO_2 reduction would be done by utilities. The 1990 utility emissions total for the ARMS region without a control program is projected to be 17,770,000 tons (see page 24). The 1990 emissions total in that area for utilities with the reduction program is 7,786,000 tons.

Question:

I. D. How much of the SO_2 emissions in each of the studied states comes from utilities?

1. Were other sources of reduction considered in your plan? Why/Why not?

Response:

I. D. ICF did not prepare a utility emission inventory in each state for us. We believe the emission inventory for utilities prepared by the Office of Technology Assessment is an appropriate inventory to use for policy evaluation purposes. This inventory appears in Table A-5 of the OTA "Staff Briefing Memo" submitted to the Committee Staff on June 2, 1982. As stated above we did not analyze the costs savings which might accrue from reducing SO_2 emissions from sources other than utilities simply because we lacked the funds to pay for such an analysis.

Question:

I. E. Did you do any calculations on NO_x emissions? Why/Why not? Do you have any?

Response:

We did not calculate NO_x emissions because we lacked the funds for such an analysis. The NO_x emissions inventories of which we are aware have substantially greater uncertainty than do the SO_2 emissions inventory. We cannot recommend any particular inventory at this time.

Question:

II. How did you choose your reduction alternatives? Please justify fully. Also include:

A. Percentage of each alternative chosen in terms of tons of SO_2 or NO_x removed?

B. Were NO_x reductions considered? Why/Why not?

C. Were intersystem or other trading schemes considered? Why/Why not?

Response:

II. EPA and DOE had previously analyzed emission reductions of 5 to 7,000,000 tons. We wished to examine an alternative which would achieve greater reductions than these but which would not be subject to the criticism that the reductions were more than needed to "solve" the acid rain problem. Therefore we selected an SO_2 emission reduction total which was less than necessary to achieve a 50% reduction in hydrogen ion deposition. The total we chose was 10,000,000 tons of SO_2.

Our analysis permitted intersystem and interstate trading of emission reduction obligations. We did so based on the current utility practice of generating electricity on a least cost basis through multistate/multicompany ownership of generating plants and interstate sales of electricity.

Question:

III. What is the total average cost per ton of SO_2 or NO_x for each alternative employed in your study? Please explain fully your accounting method (annualized, levelized, present value, etc.) and how you calculated it. Please include:

Response:

III. Our analysis concluded that the average cost per ton of SO_2 for a 10,000,000 ton reduction program would be $244 per ton in the year 1990 and $344 in the year 2000 in the acid rain mitigation region. This figure represents the average annualized costs of such a control program over the period that it is in effect. The annualized costs include capital costs, operation and maintenance costs, increased fuel costs if any, and financing costs.

Question:

III. A. Scrubber costs: capital costs (per KW), O and M costs, capacity and energy penalties. (If possible, use 500 MW unit for comparison.)

Response:

III. A. Scrubber costs are identical to those used in ICF's analysis for EPA and DOE "Alternative Strategies for Reducing Utility SO_2 and NO_x Emissions" (June 1981). They are contained in Appendix III of the "Scenario Specifications" document of that study. For your convenience a copy of Appendix III is enclosed. Tables 2, 3 and 14 of that Appendix contain detailed information on scrubber costs for existing plants.

Question:

III. B. New Plant costs: capital costs (Per KW) and M costs, percentage of these costs which are attributed to the bill as opposed to eventual turnover in generating capacity.

Response:

III. B. New plant costs are also the same as specified in the EPA/DOE Scenario Specifications Document, Appendix III. They are presented at Tables 1 and 15 of the Appendix.

Question:

III. C. Other Capital Costs: e.g., costs for boiler retrofit or ESP.

Response:

III. C. The analysis done for us did not include costs for boiler retrofit or ESP upgrades. With respect to boiler retrofit, the analysis restricted wet bottom and cyclone boilers from shifting to very low sulfur coals in the model. A discussion of this constraint is contained at pages 3-33 through 3-36 of the Scenario Specifications Document and is attached for your convenience.

Question:

III. D. Fuel Switching: include capital costs (e.g., boiler retrofit or particulate control); fuel price differential (uses 6 lb/MMBTU coal for comparison).

Response:

III. D. In addition to the constraint discussed above on switching to low sulfur coal for certain boiler types, the model also restricted fuel switching to account for long-term contracts and mine mouth power plant operations. This is discussed at pages 3-34 of the Scenario Specifications Document which is attached.

Fuel price differentials are not set *a priori* in the ICF model. The model calculates prices for each type of coal based on a set of supply curves developed for each region's coal type as a function of coal reserves data and mine engineering costing algorithms. In effect the model calculates what it would cost to mine coal of various types, adds a fair rate of return, and adds transportation costs to bring it from the mine to the power plant. The way the model calculates coal prices is discussed in more detail in Appendix II to the Scenario Specifications Document at pages II-5 through II-8. A copy of Appendix II is attached for your convenience.

Question:

III. E. Capitalization: depreciation and interest rates assumed (list these separately).

Response:

The financial parameters used in the model are discussed in the table comparing the EPA/NWF assumptions with the CBO assumptions which was attached to our summary statement distributed to the staff on June 2, 1982. For your convenience they are repeated here:

Financial Parameters

o Inflation Rate (% per year)	1981-2000 = 9.0%
o Real Discount Rates (% per year)	Coal Mine = 6.00% Utility = 4.26%
o Coal Transportation Rates -- Rail, Barge and Truck (% total real escalation)	1979-1985: East = 25.0% West = 33.0% 1986-2000 = 0.0%
o Mining Costs (% annual real escalation)	Capital = 0.0% Labor = 1.0% Materials = 1.0%
o Capital Charge Rates	
Coal/Nuclear/Combined Cycle	10.0%
Scrubbers/Particulate Equipment	12.5%
Combustion Turbines	12.5%

Question:

III. F. Total costs of removal per state studied (note above) request on explaining figures).

1. Are costs to reach SIP compliance included?

2. If you used an emissions ceiling, how much less would be the cost without the emissions ceiling?

Response:

III. F. The costs for each state vary according to the allocation formula. They are all displayed at Tables 7 through 9 of the NWF/NCAC report (pages 23 through 34).

As mentioned above emission reductions needed to comply with state implementation plans are not included in the reduction program and the costs of SIP compliance emission reductions are not included either. As mentioned above we did not use an emission ceiling in our analysis.

Question:

IV. How were rate increases calculated? (as before, please explain calculations fully.)

A. Are the increases strictly from the bill?

B. What is the percentage increase in rates in 1990 due to the reduction program alone, expressed as a percent of 1980 rates, and also as a percent of projected 1990 rates?

Response:

IV. Rate increases were calculated by calculating the total 1990 annualized costs of all utility systems in the acid rain mitigation region with and without the SO_2 reduction program. The difference in these total costs calculations was then expressed as the percentage increase in the projected 1990 electrical rate. The same calculation was done for the year 2000. The percentage rate increases which are presented in our report are strictly due to the 10,000,000 ton SO_2 reduction program. The model also assumed that there will be increases in electricity rates due to a large number of other factors during that period. ICF did not calculate for us the rate increase expressed as a percent of 1980 electrical rates.

Question:

V. Please bring any sensitivity analyses or other runs that you have prepared.

Response:

V. Prior to preparing the November 14, 1981 report for us ICF developed several preliminary analyses. These are contained in three documents which are attached:

1. "Costs and Coal Production Effects of Reducing Electrical Utilities Sulfur Dioxide Emissions" (August 1981);

2. Memorandum from Stauffer to Hawkins dated September 29, 1981;

3. "Costs and Coal Production Effects of Reducing Electric Utility Sulfur Dioxide Emissions" dated November 12, 1981.

These analyses examine the following programs in addition to those presented in the November 14, 1981 report:

a. An initial compliance date of 1985 rather than 1990;

b. A program requiring actual 85% control of utility plants with annual emissions greater than 100,000, tons per year. This option is contained in the August 1981 document and is titled "Scrubbing." This option is different from the allocation formula presented in the November 1981 document labelled "85%/1/7 lbs.-30-day average allocation." The "scrubbing" option would actually require 85% removal on the identified plants and would not permit trading to discharge that reduction obligation. The 85%-1.7 lbs allocation formula is purely for the purposes of allocation and the reduction obligation could be discharged through intersystem and interstate trading.

c. NSPS Offsets: This option would permit utilities in the ARMS region to increase emissions at NSPS plants if the increases were offset on pound per pound basis with emission reductions at existing units above and beyond the reductions required by the 10,000,000 ton reduction program.

Question:

VI. Please compare your assumptions with those made in the CBO study "The Clean Air Act, the Electric Utilities, and the Coal Market." Explain differences?

Response:

VI. The requested comparison is attached in Table A "Comparison of Major Base Case Assumptions." Please note that all dollars have been escalated to early 1982 for comparison purposes. In addition, since the CBO study examined new power plants its scrubber cost figures are based on a new coal-fired plant meeting the 1979 NSPS (70-90% scrubbing) and equipped with particulate control system to meet 1979 NSPS. To provide a basis for comparison the EPA/NWF scrubber cost figures are presented for the same configuration. All of the assumptions in Table A were identical to those used by EPA and DOE so that our analysis could be compared to the prior analysis. Differences between those assumptions and the CBO assumptions are due to CBO having chosen different assumptions. The principal differences are in world oil prices and higher after 1990) scrubber costs (CBO is 20-20% higher), industrial coal use demand (CBO is lower), steam coal exports (CBO is higher), inflation rates and mining costs escalations (CBO is lower).

Enclosures:

1. ICF Report for NWF/NCAC "Costs and Coal Production Effects of Reducing Electric Utility Sulfur Dioxide Emissions" dated November 14, 1981.

2. ICF Report for EPA/DOE: "Scenario Specifications, Alternative Strategies for Reducing Utility SO_2 and NO_x Emissions" pages 3-33 through 3-36; Appendix II, and Appendix III.

3. ICF Report for NRDC "Costs and Coal Production Effects of Reducing Electrical Utilities Sulfur Dioxide Emissions" (August 1981).

4. Memorandum from Stauffer to Hawkins, September 29, 1981.

5. ICF Report for NWF "Costs and Coal Production Effects of Reducing Electric Utility Sulfur Dioxide Emissions" dated November 12, 1981.

5. ICF Report for NWF "Costs and Coal Production Effects of Reducing Electric Utility Sulfur Dioxide Emissions" dated November 12, 1981.

6. Table A, "Comparison of Major Base Case Assumptions."

JUNE 3, 1982

Mr. **Moore**. Most of the people who will be making presentations today are strangers to us personally. Therefore I will introduce myself. My name is Curtis Moore, I am associate counsel for the committee. To my left is Kathy Cudlipp who is the counsel to the committee.

This is the second of 2 days of inquiries into the cost implications of acid rain control proposals.

This is a rather peculiar beast. We have never done anything quite like this before. It is somehwere halfway between a hearing and a staff briefing. The people that are in this room fall into several groups. One, the committee staff who are actually employees of the committee itself, second, the personal staff of individual members of the committee. Third, the staff of the four arms of the Congress, the General Accounting Office, the Congressional Research Service, the Congressional Budget Office, and the Office of Technology Assessment. They have done all of our work in this area.

Yesterday we heard from those institutions which had done, for lack of a better term, macrostudies of the costs of control, including institutions like the Edison Electric Institute, Peabody Coal, the Department of Energy, and so on. The purpose of today's meeting is to hear from individual companies and systems. There is one system that was unable to be at today's meeting and we will be meeting with them probably not in this kind of a format next Wednesday at 10:30 and that is the Tennessee Valley Authority.

I am not sure exactly which systems we have here today because George Freeman made the arrangements and it would be appreciated therefore if, in just a minute, George would tell us exactly which systems we have here. We do have a reporter. So as you ask or answer questions later in the morning, it would be helpful for you to identify yourselves. Each of you is asked to make a presentation that is no longer than 10 minutes and if you have one, a two-page summary of your longer study. You are asked to submit the longer study for the record. What we will do is go through the entire list of witnesses and then after everybody has said his piece we will have questions and answers.

The exception to that will be that Mr. Joe Dowd, who for personal reasons has to leave early, will start. We will ask whatever questions we have if any. He will leave and then we will continue and complete the rest of the panel and have questions and answers. So George if you could identify for us the particular systems and companies we have here it would be helpful.

Mr. **Freeman**. All right. I will do that. Then I have a list of the names and titles and companies of different witnesses and there will be one more other than the people listed on this list. I will sort of read them in the order in which they will make their presentation.

Joseph Dowd, who is senior vice president and general counsel of American Electric Power and as many of you may or may not know, American Electric Power operates in the western part of the State of Virginia, a substantial part of the State of West Virginia, part of Kentucky, a substantial part of Ohio, and an area in Michigan and Indiana. He will speak first.

Then there is Dr. Charles Goodman who is manager of air, water and thermal sciences program of the Southern Co. as most of you may know operates substantially in the almost entire State of Georgia, all of Alabama south of the TVA territory and part of Florida, substantial parts of Mississippi; Dr. Ali, manager of environmental programs for Public Service of Indiana which is here; James Pennington, vice president of financial operations of Public Service of Indiana is with him and both of them will speak for their company.

Robert McKnight is chief environmental engineer, Indianapolis Power & Light. You have substantially the whole State of Indiana with minor exceptions covered today. We also have Charles V. Runyon, manager of environmental special projects departments, Ohio Edison. So again we have substantial coverage for that State. Jerrel Smith is manager of environmental affairs, Union Electric Co., operating not only in a substantial part of Missouri but also a part of Illinois, and Jack Kaslow, who is senior vice president, New England Electric.System, which gives us substantial representation here, and then Kurt Hansen is here from the New York Power Pool.

So I think we have got a representative slice of the major systems in the country that would be directly affected by this legislation.

Joe, will you tell us what AEP's estimates this cost would be and the basis for the assumptions?

PRESENTATION OF AMERICAN ELECTRIC POWER CO., BY A. JOSEPH DOWD, SENIOR VICE PRESIDENT AND GENERAL COUNSEL

Mr. Dowd. Thank you, Mr. Freeman, Mr. Moore, ladies and gentleman. Before getting right down to the bottom line on the AEP cost study I would like to point out that we do appreciate the opportunity of appearing before you to get across what we think is the effect and that is that the companies specific studies will generally reflect a more realistic level of the costs that would be imposed by the Mitchell bill were it to be enacted.

It is my understanding that these companies specific studies were all conducted, as far as I know, independently of each other. This makes comparison difficult and that is a negative. But I submit that it may also have some virtues. Companies took different approaches to this. They did it on their own in the way that they thought best and they generally came up with, I think in all cases, levels of cost impact that are substantially higher than the macroeconomic models that you heard discussed yesterday.

I obviously can't and won't speak for the other companies. What I have to say relates only to the AEP study. But in my view the basic reason why company-specific studies are substantially higher than the macroeconomic model is that they come closer to reflecting the real world.

For example, the people who conducted the AEP study, it was in-house, they know the AEP system better than any macroeconomic model, I don't care how good. We know the age, we know the condition of each of our plants, we know the configuration of each plant.

This is very important. We know whether there is space problems with respect to scrubber installations. This would affect retrofit costs and even the feasibility of scrubber retrofits. We know whether there are plant systems that would have to be relocated if retrofits were to take place.

This, again, is a major cost factor. We are familiar in detail with the topography of the plants and of the surrounding terrain. This is directly relevant to the feasibility and/or the costs of sludge disposal from scrubbers. We know our boiler designs and what kind of coal we can and cannot burn and this is directly relevant to whether or not fuel switching is a feasible alternative at a particular plant.

In the case of mine-mouth plants tied to the specific source of coal, such a plant may be geographically inaccessible to other sources of fuel and therefore switching may not be feasible or may be enormously expensive because you may have to construct additional transportation facilities to get the fuel into the plant.

We are familiar with the precipitative performace on our units. Where they are marginal in terms of compliance and where you are thinking of fuel switching going to a lower sulfur coal, you run the possibility or the probability of throwing those precipitators out of compliance. This means substantial additional cost in terms of precipitativor retrofit in the fuel switching situation.

So the premise of our study was really ground floor feasibility considerations. Our figures are very high; very high: $7.2 billion capital costs for the system; $2 billion annual costs.

Mr. MOORE. How much is that cost per kilowatt of your generating capacity?

Mr. DOWD. I am sorry, I don't have that figure.

Mr. MOORE. Could you provide that for the record?

Mr. DOWD. Yes, certainly. But this translates to bear in mind when we look at the size of these costs that AEP is a very large system. We have got 22,000 megawatts of capacity, about 19,000 of which are fired by coal, must of its Midwestern coal. Eighty-seven percent of our capacity is coal fired. Under the Mitchell bill, if we had to implement it, we would have to retrofit, in our view, 16 units, 10 plants, a total of 12,775 megawatts. We fuel switch at 4 units at 3 plants, 2,800 megawatts and we would prematurely retire from service 7 units at 4 plants totaling 1,075 megawatts.

Let me tell you how we went about the study. First, we accepted the ICF tonnage reduction figures that were developed for EEI. And we accepted ICF's allocation of those tonnage reductions among the various 31 States in the ARMS region. We then made some assumptions. We assumed that all the SO^2 reduction would be laid off on the electric utilities. This was an assumption ICF made.

We made it independently. It is our perception of the political process, it is our perception of experience over the years, really, and concepts of administrative feasibility in controlling a few large units rather than a multiplicity of smaller units that the probability is that these emission reductions will be concentrated entirely upon electric utilities. It is debatable. This is what we assumed.

Second, we assumed that the State agencies, when they took their allocated emission reduction, that they parceled it out among the electric utilities within their jurisdiction on a pro rata basis. They can do it on a cost-effective basis, but it is difficult for us in making our study to figure out how that woud work. So we simply assumed that Ohio had to reduce its emissions by 85 percent, the AEP facilities within the State of Ohio would have to reduce their emissions by 85 percent.

Systemwide, I might add, the SO^2 emission reductions that we will have to accomplish under Mitchell would be 71 percent; 71 percent of existing emissions would have to be cut.

We also assumed no interstate trading. Again, this can be debated but we have difficulty in terms of practical politics, believing that a State is going to reduce more than it has to, without somehow being compensated by a neighboring State, and if it is compensated, then the whole thing is thrown off. Very important, and I think this is something that is of great interest to this group.

We assumed a regional coal constraint. Four of the five States in which we have generating capacity are high-sulfur coal-producing States, States in which that industrial activity is very significant to the economy of those States; Ohio, Indiana, Kentucky, and West Virginia all substantial high-sulfur coal industries.

On the basis of our experience over the past 10 years, we know darned well that as a practical political matter, we will never be permitted to drop our historic fuel supply and switch to the West. That will never happen. Even forgetting about section 125 of the Clean Air Act, which says that you cannot switch away from your historic local coal supply in order to meet environmental regulations, if to do so creates economic disruption or dislocation of a local community which it most surely will.

We have switched fuel in our study at four plants. We switched to a regional fuel, West Virginia fuel we hope we would be able to retain, and these were plants where there were space problems.

We couldn't put in scrubbers. We were really faced with the alternative under this scenario of shutting them down or burning a lower-sulfur regional coal.

We figured we probably could get away with that limited amount of fuel switching but not much more than that.

We also placed in our scenario the lost generating capacity, I say lost generating capacity, 10 percent is lost as a result of the scrubber retrofits.

As you know, scrubbers consume electricity. Five percent, we figured a 5-percent auxiliary power requirement for scrubbers. We also figured that as a result of the operation of scrubbers, we are going to lose about 5 percent of our plant's availability. That is 10 percent. That 10 percent results in about $345 million of annual costs which is 17 percent of our total $2 billion annual costs. We would also replace the 1,075 megawatts of prematurely retired generating capacity. This results in a $290 million annual cost, 14.6 percent of our $2 billion annual cost. The total cost on an annual basis for the new capacity is $635 million or 31 percent of our annual cost of $2 billion.

I would point out to you that while the AEP system presently has generating capacity reserve of approximately 40 percent, by the early 1990's our capacity reserve is expected to be below 20 percent and on that basis as a public utility with the public utility responsibilities, we felt constrained to plan an earnest scenario, the replacement of the generating capacity that would be lost as a result of the Mitchell bill.

If you have another minute or two, there was a Congressional Research Service report that evaluated various cost impact studies relating to acid rain control. They gave extremely short shrift to the AEP study. They said it didn't measure up on a number of counts. They said in terms of completeness, reasonableness of assumptions, data methodology, they were going to exlude it from their study.

On the basis of my experience, that is really one of the most unhappy studies that I have ever seen, very, very sorry job. They first said it was incomplete because it looked at only five States. Sure, it looked at only five States. It was evaluating the impact of the Mitchell bill on the AEP system. We have generation in five States. That is not an incomplete statement. They said they did not want to look at it because it evaluated the Mitchell bill, not the Moffett bill. So did the ICF studies. Every one evaluated the Mitchell bill. They didn't like it because it took into account the moratorium on emission increases, the fact that you have to offset for emission increases. That is not in the Moffett bill, it is in the Mitchell bill. They didn't like the AEP study on that basis. ICF did the same thing. They said there were questionable assumptions. One of them was the exemption of industrial emissions. ICF exempted industrial emissions. They analyzed that, all right. They talked about the inclusion of future plant emissions as a defect in our study.

Of course it isn't. It reflects the Mitchell bill. They said that we limited our alternatives to fuel switching FGD retrofits.

The implication was that we did not look at coal, coal cleaning, that we didn't look at least emission dispatching and that we didn't look at conservation. Conservation is built into our low forecast. As far as coal cleaning is concerned, we do as much coal cleaning as any electric utility system in the country. We don't have too much further to go. When you are talking about massive SO^2 emission reduction of 70 percent, you cannot deal with that coal cleaning in a few thousand tons. It would probably get us no more than 4- or 5-percent reduction in SO^2 emissions.

If you are going to put on scrubbers, put on scrubbers. This was our approach. So we do not regard these as particular valid criticisms. Then they said we were emphasizing high-cost approaches, FGD retrofits instead of fuel switching. The reason for that is we operate in Midwestern States with significant high-sulfur coal industries and by golly, they are going to resist any fuel switching and they have, too, section 125 available as enacted and they are going to use it.

I guess I would like to close by indicating that, for example, the State of Ohio has at the present time an unemployment rate of about 12.5 percent. It is the second highest in the Nation after Michigan. The costs that we are projecting are enormous. They are too high for this reason or that. Maybe they should be, instead of $2 billion a year, $1.5 billion, maybe they should be $1 billion. We think that they are $2 billion. But whether it is $2 billion or $1 billion, they are absolutely enormous and we would just ask the Senate to go slow.

Thank you.

Mr. **Moore**. I would like to ask a couple of questions. You indicated that you would be spending roughly $7.2 billion to comply. And you also indicated that you would be scrubbing about 12,775 megawatts. Not knowing how you have allocated any of these costs, it would appear, assuming that the bulk of your capital costs are associated with scrubbing rather than fuel switching, that you are estimating right around $500 to $600 a kilowatt for scrubbing. It is my understanding that the usual costs associated with scrubbing is $100 to $200 per kilowatt. So if you could provide us with, as I previously requested, the cost per kilowatt, plus a specific explanation on what your cost figure is and how you arrived at it.

Second, you indicated that some plants would be shut down. Would you please provide a list of exactly which plants would be shut down, their age, their capacity, the number of pounds of sulfur per million Btu and the expected future life of those plants absent an acid rain control bill? Next, I would appreciate knowing your system-wide electricity rates, and if that varies State by State. We would like the State-by-State reduction rate as well.

Next, I would like to know the system emission rates and those rates plant by plant. Obviously that repeats to some degree question No. 2. Since my understanding is that you have a fair number of mine mouth generating facilities, I would be interested in knowing what the AEP coal holdings are and what percentage of your coal-fired capacity comes from AEP-owned or controlled coal since I assume that is why, it is for those reasons that you would prefer to scrub and burn your own coal or not, but state whether that is the reason you presume scrubbing will happen.

Sixth, what are your growth-rate assumptions and your reserve margin as well?

In addition, I assume that you had distributed to you the 2-page agenda which was provided to witnesses yesterday. You do not have that?

Mr. **Freeman**. We were unable to get that to him because of special circumstances.

Mr. **Moore**. We would appreciate your responding in writing to each of those items so that we can determine what is going on.

Finally, before I throw this open to the other folks, the thrust of what you have said is that AEP at least would comply with a mandated reduction program by scrubbing, not switching; is that right?

Mr. **Dowd**. We would much prefer to switch. It is much more economical at existing powerplants. We just do not think that we will be permitted to do so.

Mr. **Moore**. That is highly relevant to the assertion of the United Mine Workers and Peabody Coal, that there would be severe employment dislocations. I would assume that you would have an increase in coal consumption because you would have a slight decrease in efficiency which would require increased coal combustion; is that right?

Mr. **Dowd**. I think that is probably true.

Mr. **Moore**. Could you indicate what you would anticipate in terms of coal purchases and what coal markets those would come from?

Mr. **Dowd**. I suppose I could respond to some of them now. It depends on how you want to proceed, Mr. Moore.

Mr. **Moore**. Lee Fuller of Senator Bentsen's staff quite properly observes that the question on the date on which you would expect those facilities to be retired with and without acid rain control legislation is a generic question that we would like all of the utilities to answer, not just American Electric. It came up now, of course, because American Electric, Mr. Dowd, is leaving, but in case we do not get around to it, please make note that we would like to know the age, capacity, sulfur emissions, expected future life with and without acid rain control provisions for each of your plants and we probably will tack on some more information to that as the morning wears on.

Mr. **Freeman**. Curtis, I think that Mr. Dowd could respond at least preliminarily and generally to several of these inquiries, since he has to leave, if his inquiry might be relevant to similar questions which you might ask of others.

Mr. **Dowd**. Whichever way you want to proceed. I can respond to some of the questions. Some of them I will have to provide to you in writing.

For example, on scrubber cost, the average scrubber costs is $321 per kilowatt. I understand what you are getting at. You divided the balance of about $1.4 billion annually—no. But I think I can get you that; $321 per kilowatt is the average cost. That included things like the sludge disposal systems, it included looking at whether you need to put up a new stack with an acid resistant stack liner when you put a scrubber on it. It looked at the relocation of other systems at existing plants, reheat fans that would be required. It was a comprehensive of real world analysis of specific situations at our plants and wasn't just the scrubber hardware retrofit.

Mr. **Moore**. We would like you to break that down in detail. The Wisconsin PUC analyzing what the cost of a control program might be in Wisconsin assigned two possible, upper and lower range of scrubber costs of $118 per kilowatt at the lower range and $230 per kilowatt at the upper range for capital costs.

Obviously, your estimate is 50 percent higher from their highest estimate and my understanding is that their estimates do include the costs of flue lining, sludge disposal facilities, and that sort of thing. We would be interested in knowing specifically what items are included in your costs.

Mr. **Freeman**. If we could also have a copy of the Wisconsin letter, we might be able to be more responsive in pointing out, in responding to your question here. It may be one of the main factors that AEP's cost is by and large very high-sulfur coal.

If the Wisconsin coal is lower sulfur coal, then that would easily explain 150 percent differential at the higher level.

Mr. DOWD. The only other thing I would mention is that our rates are set on a State-by-State basis. They are not systemwide. We can get you the information on that; the growth assumptions.

Actually our growth assumptions, our recent 10-year forecast, we had three scenarios.

One was a 2.2 percent growth rate, one was a middle one, 3.1 percent down from, I believe, 3.6 last year and the highest growth rate scenario was about 4.2 percent. But we can get you additional information on that also.

I think that is really all I want to respond to. There is quite a list here. I will try to get that information. I am not sure I took it all down.

Mr. MOORE. We will get it out of the record.

Mr. FREEMAN. I will get together with Curtis.

Mr. DOWD. After I leave, if there is anything else you need of me, George will assist me and we will get that for you too.

Ms. PFIFFERLING.[1] The plants that are prematurely retired, the way in which you accounted for the costs of that retirement in your projections, just a quick calculation showed that if the $321 figure you just gave us is multiplied by the installed generating capacity, we get about $4 billion of your $7.2 billion capital cost which appears to be the scrubber portion.

Is the other portion related to those prematurely retired plants?

Mr. DOWD. It is related to the replacement of lost generation. Part of the generation that is lost is related to the prematurely retired plants, 1 through 75 megawatts.

The other portion of our generation that is lost relates to the fact that when you backfit the 16 units with scrubbers, those scrubbers suck up 5 percent of the capacity of that unit in their operation and they also will result in lower availability of that unit because of the problems that we experience in operating units with scrubbers.

We assume 5 percent less availability on our units. So there is 10 percent of the 12,000 somewhat megawatts that will be backfitted with scrubbers. So the new capacity—I think the basic capital costs consist of the scrubber, retrofit costs and the replacement of the lost generation, both the premature retired plants and the loss of generation due to scrubber operation.

Ms. PFIFFERLING. Do you know whether the calculations would include only those years that were involved in the premature retirement?

Maybe the information that Curtis has asked for will address that.

Mr. DOWD. The life of generating units these days is becoming increasingly flexible or elastic because we are trying to hold them together just as long as we can because the building of new capacity is so onerous and so burdensome and the environmental requirements are also making it very costly.

So I think not only AEP, but other electric generating systems are endeavoring to maintain their old plants in service for just as long as they possibly can; in many cases, going well beyond the conventional depreciable life of the facility, whether 50 or 40 years.

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[1] Sueanne Pfifferling, Senator Moynihan's staff.

There is a lot more elasticity there today than there used to be but we will endeavor to analyze that. I am not sure how this was done.

Ms. **Pfifferling**. I guess what I was interested in is the bottom line, if the plant was retired.

Mr. **Dowd**. It is not right to take full credit. Yes, exactly. I understand.

Mr. **Frankel**. Richard Frankel from GAO.

You mentioned just now that you are stretching out the life.

Do you think that is likely to have implications or could you comment on what implications that would have to the expected decline in the utility emissions over time with the replacement capacity?

Mr. **Dowd**. It would have a negative effect, in the sense of a bad effect. If we were able to build new plants more expeditiously in a less costly way, we would retire the older existing plants that throw out more pollution on a much more timely basis.

We want to keep the older higher polluting plants in service for a longer period of time and that requires——

Mr. **Frankel**. The other thing, the question that has come up before, the construction-work-in-progress issue and whether that goes to the rate base.

Do your CWIP's allow pollution control equipment?

Mr. **Dowd**. We are in seven States. This is not my particular area of expertise. I would have to say it varies all over the lot.

In Indiana, I don't think they are allowing anything in. In Ohio, we may be getting something and, of course, the FERC allows pollution control as one of the exceptions but it varies all over the lot. We get different treatment in different States.

All I can say is I know in Indiana we get nothing and they just reached that determination, that the utilities get no CWIP treatment at all.

In other States, we may get some. I think in Ohio we do get some.

Mr. **Freeman**. We will supply that information for the record when we submit the other information, the information that has been requested for an AEP.

Mr. **Frankel**. Just to see if I am clear.

When you talk about replacing capacity what you are doing is looking at the entire system availability reduction beause of the scrubber problem and adding capacity generally to bring the system margin back up; is that right?

Mr. **Dowd**. Yes. That is part of it.

Mr. **Frankel**. Pardon?

Mr. **Dowd**. That is part of the additional new capacity.

Mr. **Friedman**. I have a couple of questions.

The 10-percent penalty for scrubbers seems rather high, much higher than, say, some of the TVA estimates I have seen.

Could you provide us with some——

Mr. **Dowd**. I think it is generally—you have to understand that 10 percent is 5 percent for auxiliary power requirement which I think is a pretty generally accepted figure in the industry, anywhere from 4, to 6, to 7 percent.

We took 5. I don't think many people will quarrel with the 5-percent scrubber auxiliary requirement.

The other 5 percent relates to the loss of reliability on the unit as a result of scrubber malfunction from time to time.

I think that is probably not a figure that too many people would quarrel with.

Mr. Moore. Is AEP operating scrubbers right now?

Mr. Dowd. Yes.

Mr. Moore. Would you please provide information on the age of the plant and the reductions in operating efficiencies that result from the scrubbers?

Mr. Dowd. We inherited one scrubber when we acquired the Columbus, Ohio, electric system 2 years ago and I think that scrubber has been there only a few years.

We will get the information on that.

Mr. Friedman. Can you also provide us with your construction costs or capital costs for the last scrubber installed or the last two or three installed?

Mr. Dowd. I think there may have been only one scrubber that we inherited. We can get you the costs on whatever scrubbers we have.

Mr. Moore. Are you saying the system operates only one scrubber?

Mr. Dowd. That is right.

Mr. Freeman. I think you have to bear in mind two things. When you retrofit a scrubber as distinguished from building a new plant with a scrubber, you have a lot of problems that you normally do not have. You have different constraints.

You cannot optimize the design. You have to sort of force it back in. That doesn't create substantial additional costs.

Mr. Friedman. You may have to and it would be helpful if you did provide some details, whether there were constraints.

Mr. Dowd. The Columbus and Southern scrubbers that I mentioned whether one or more than one were built with the plants. There were not retrofit jobs. They were installed as the plant was being built. So their costs as Mr. Freeman mentioned would be somewhat different.

Mr. Moore. It would be interesting to know where you got your information since TVA is in the process of retrofitting and has retrofitted and that the reason we wanted TVA here, frankly, is because they are a kind of quality control of the industry.

Mr. Freeman. I think one thing you should bear in mind is that when we talk about retrofit costs and scrubber costs, we still have competitive pricing in that industry but there are real doubts about capacity of that industry to respond in a timely basis.

That was one of the major concerns which we had addressed in the recent resource performance standard rulemaking for percentage removal by standard.

If you had massive retrofit of scrubbers on top of the scrubber orders that are now in place for new plants, we might have a situation where the profit margin would go up considerably in that industry and, therefore, the costs which have been based on a pretty close profit margin apparently in that industry would have to be substantially revised.

so you could create an artificial shortage that would disrupt the market and make all of the costs go up.

Mr. McKnight. Could I add something there?

One of the costs on scrubbers, too, is, you have to look at——

Mr. Moore. Please identify yourself.

Mr. McKnight. I am Bog McKnight with Indianapolis Power & Light. We operate one scrubber and have another one under construction.

When you build a scrubber like when you build anything, you can go with more expensive materials and less expensive materials; the trade off being how long those materials would last.

Something Mr. Doud referred to would be the stack liners and those type of things. If you go stacklining, carbon steel coated with fiberglass and things like that, that is less expensive. But from our own experience, we have had to replace this lining every 2 years, and it is a very suspect as to whether our stack will last very long at all or not.

The other choice, when you build a stick, you can go in there with some very expensive alloy steel and pay substantially more. So if you end up with looking at 100-kilowatt scrubber, you may have a 100-kilowatt scrubber that is good for 6 months and then will be flat on the back half the time.

So I would encourage you as you look at it to understand that there are different philosophies in building these.

You can build them and come up with a reasonable level of maintenance or you can build them with a lot of maintenance and the cost between those scrubbers will be significantly different.

Mr. Friedman. While we are on scrubber costs, do you put in scrubber spares? Do you assume they would be necessary?

Mr. Dowd. Again, the AEP system has never itself——

Mr. Friedman. In your cost calculation?

Mr. Dowd. Our analysis is that we will use spare modules because we understand that the industry experience, especially on high-sulfur coal, is that they have to shut these things down, they have to go in there, 25 or 30 guys at night with jackhammers and clean them out. Unless you have these spare modules your unit would be down while you do this. So if we were to retrofit with scrubbers we would have to apply the spare module concept. That is in these costs.

Mr. Freeman. The problems of scrubbing high-sulfur coal were pretty well brought out in the recent NSPS rulemaking and then in the experience of the industry after those rules were first proposed our most recent survey of the utility industry shows that only 2 permits have been applied for since passage of the 77 amendments and the proposal of the percent removal standards by EPA where the utility industry has tried to burn or applied for permission to try to burn high-sulfur coal.

By that I mean the high-sulfur coal, 6 percent sulfur or above. There is one unit of 450 megawatts by a co-op in southern Illinois and one for about 400-megawatt high lignite unit in I think it is either Louisiana or Arkansas. So even though we do have a lot of scrubbing experience or are beginning to get it in the utility industry, because the problems multiply substantially the higher you go up in the sulfur content, particularly the reliability of maintenance problems, the costs that are normally associated with scrubbers in the lower range really are not extrapable, can't be extended across the board to these high sulfur coals.

A lot of those coals that AEP would be burning is probably in that higher range.

Mr. **Friedman**. When you say high, are you talking about 6 pounds or more?

Mr. **Freeman**. Six pounds or more.

Mr. **Friedman**. I believe some of the TVA estimates are with 6 pounds.

Mr. **Freeman**. It would be interesting to know and I think that is something you should follow through specifically with them is the percent sulfur in the coal. I think a lot of it, I pointed this out yesterday, fall in the habit of talking about low sulfur coal and high sulfur coal as if there were two things out there. There is a continuum. We get into those higher sulfur coals and that is really starting at about 5 percent and on up. The experience with scrubbers below there is really not directly extrapable to the higher coals.

Mr. **Friedman**. It is my understanding that in the Petro survey done for EPA at least one of the scrubber costs in terms of dollars per kilowatt that I saw on some of your previous documentation was twice as high as the historical high on any scrubber that has been installed in the United States so far. I don't remember what pound coal that was. But I assume that was a small plant with a very high coal.

I am wondering whether you could provide us with some details, why that would be twice as expensive as any other scrubber that has been installed?

Mr. **Freeman**. One of the things you might do since you are in a better position to get an answer than we are is to ask EPA, ask Petro to give you the sulfur contents of those coals which if any of those units were retrofitted.

Mr. **Moore**. You will be providing the information on the AEP cost estimates and the assumptions which underlie those cost estimates which is what I think Bob is driving at.

Mr. **Friedman**. One of the things that all of the macromodels have trouble with is exactly what does the utility have to pay for capital, how much are you paying per year on your capital investment? Could you provide us some real world details as to how quickly you depreciate, whether you use pollution control bonds?

Mr. **Dowd**. We use pollution control bonds. We have historically done that. I can get you information on our financing. I will say that our annual carrying charge rates on the new capacity costs was 21.64 percent. I will get you the other information on our capital costs.

Mr. **Friedman**. I think that is a bit higher than any of the macromodels, at least it is a bit higher than some estimates, EPRI estimates as well. I am just curious why.

Just one other question. When you said you used ICF/EEI run, we heard four different ones yesterday running from 13-mill reductions down to 8.1-mill reductions, given the 71 percent I assume you used the 13 million tons.

Mr. **Dowd**. Thirteen million tons.

Mr. **Friedman**. Would it be possible to redo that at the lower one, what results in 6.1, just eliminate those plants that would be eliminated to meet those?

Mr. **Dowd**. Is that an ICF model?

Mr. **Friedman**. Yes. The same assumption, different allocation formula for emission.

Mr. **Dowd**. Were they addressing the Mitchell bill?

Mr. **Friedman**. Yes, different interpretations of the bill.

Mr. **Freeman**. Let me ask counsel for the committee whether we have correctly interpreted the bill as now before the committee as imposing a cap on existing NO_x and SO_2 emission itself and a requirement that they be offset?

Ms. **Cudlipp**.[3] I think you have got a cap on the emissions, that there is a reduction, absolute reduction from the current level that would have to be implemented by the end of the decade when it is required.

Mr. **Freeman**. So unless the bill is changed the 13 million would be the correct figure for us to go with, assuming you are not vouching for how you get the makeup. In other words, it is 16 million plus x and ICF is—x is what is necessary to compensate for the cap.

Ms. **Cudlipp**. Depending upon what that number is.

Mr. **Friedman**. That is right. But if ICF estimated that correctly or whatever, anybody wants to put it in there, that would be all right.

Mr. **Cummings**.[4] I don't think that is the only interpretation the language is subject to. So I think it is perfectly legitimate to ask what the cost implications of other interpretations might be.

Mr. **Dowd**. It would be very helpful if this aspect of it were clarified.

Mr. **Cummings**. I understand how important it is.

Mr. **Dowd**. Congress to know before it acts on the bill.

Mr. **Cummings**. It would be useful to know what the cost implications of the other interpretations would be.

Mr. **Freeman**. We will go back and try to look at the 8.1. At the same time we produce that data we will produce clarifying language for the staff.

Mr. **Dowd**. On this request of ADP, I want to qualify my response. I am not sure how much work is going to be involved. We have got a long list here. We will do our very best to get it to you. This is an additional study. It may be something that our people can knock off in reasonable time and without the expenditure of enormous effort. If it is we will certainly get it to you. If on the other hand it is a major undertaking I just don't want to promise.

Mr. **Moore**. I assume that as to the capital cost of scrubbing you did go through this process in order to assure that your estimates were accurate and you have provided those estimates to the Congress. I trust that you do have that information on the shelf and readily available.

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[3] Katherine Y. Cudlipp, counsel, Committee on Environment and Public Works.

[4] Philip T. Cummings, minority counsel, Committee on Environment and Public Works.

Mr. Dowd. I am not sure that you are correct. I think we addressed the Mitchell bill with the offset, we took the ICF numbers and we applied them State by State.

Mr. Moore. You did calculate how much a scrubber costs and what the components of that cost are, didn't you?

Mr. Dowd. Of course. If you are dealing with a lower number your strategy is going to be somewhat different. It may be 8.1. We may be able to come up with this by just pealing off the most expensive jobs. It may be a very simple matter. But I can't sit here and tell you that we have got all of this stuff on the shelf for 4 million, 8 million, tons or anything else. We did a specific study of the impact of the Mitchell bill as we understood it.

Mr. Freeman. What he does have and we will give it to you rather than on the 15 million, because that was the basis——

Ms. Cudlipp. That is the first most important set of questions but clarifying assumptions that have been asked for, 13 million, it would be helpful to us if it can be done for the alternative interpretation for the 8.1

Mr. Moore. I do want to make an observation about this incremental 3-million tons. Everybody asserts that at least the levels which are sought by the various acid rain control strategies will be achieved naturally as a function of equipment replacement and compliance with percentage reduction. So that that incremental 3-million tons is one which will be achieved through the installation of equipment that has scrubbers in it.

I mean the cap will come about naturally and it is therefore—am I wrong?

Mr. Jewett. It might come about by the year 2,015. But it won't come about——

Mr. Moore. It is not a question of whether it will come about, it is a question of when. I would gather that even if we were to leave or relax the new source performance standard you would still feel constrained to rely on scrubbing and your locally available Midwestern coal to achieve it. Is that correct?

Mr. Dowd. At new plant?

Mr. Moore. At the plant. What you have said is political considerations would prevent you from coal switching.

Mr. Dowd. And section 125 which after all is a statute that is in the Clean Air Act and Ohio has availed itself of once and will in all probability do so again. But the economics of low-sulfur coal versus constructing a new plant with scrubbers is somewhat different from the existing plants situation. When you say relax the new source performance standard I am not sure in what respect.

Mr. Moore. I am sure George has a good idea. I am sorry.

Mr. Dowd. Get rid of a percentage removal?

Mr. Moore. Yes, if you just went to a number.

Mr. Freeman. Under those circumstances, you see in his system he has some optional working locations new plant and he doesn't have the disruption of the coal supply problem that you have when you are dealing with existing plants. You remember that the Mason-Dixon Line of high-sulfur coal goes through the middle of West Virginia. So he would have the option of locating his new plant in southern West Virginia or Virginia or in eastern Kentucky as distinguished from building his new plant in Ohio or Indiana.

Mr. Dowd. Of course this is what we have done. Our newest plant, 1300 megawatts, went into service about a year and a half ago in West Virginia, burning West Virginia conforming coal. We have been looking at another plant in eastern Kentucky that would burn indigenous low-sulfur coal from that region. But it is really a very different situation when you are talking about fooling around with existing plants.

Mr. Moore. So depending on the design of a reduction strategy, it is possible that you could comply by coal burning as opposed to scrubbing? I understand the way the bill is now written you presume you will scrub. But what you are also saying is that if it is altered in a certain fashion it is possible that you might be able to comply by burning coal as opposed to scrubbing.

Mr. Dowd. Are you talking about complying with an acid rain control bill or complying with new source performance standards?

Mr. Moore. There may not be a difference.

Mr. Dowd. There is a 70-percent emission reduction that would be imposed upon us by the Mitchell bill at our existing plants.

Mr. Moore. But you are going to eventually replace those anyway and you will achieve that 70-percent reduction in 2020, 2010, 2,000?

Mr. Dowd. In 40 years.

Mr. Moore. The average plant was built in the 1950's and 1960's?

Mr. Dowd. And 1970's.

Mr. Moore. So you are talking 1990's.

Mr. Dowd. We are talking a long time.

Mr. Moore. That is the reason I think, Senator Mitchell thinks that we can't afford to wait a quarter of a century to replace the facilities.

Larry, did you have any questions?

Mr. Parker.[5] I hate to burden you with any more questions. The high sulphur industry is important. So a couple of requests are like how much megawatts does AEP currently use to wash their coal?

Mr. Dowd. I can get you those figures. I would say 80 or 90 percent of our coal is washed. Thirty-three percent or perhaps 35 now is so-called captive coal. This was one of the questions earlier. Thirty-five percent is our own coal. All of that is washed and washed at a very high level of technology. Much of our contract coal is washed, we are moving, getting more and more washed coal. But I can get you specific figures on percentages and so forth.

Mr. Freeman. I might make this comment on coal washing. The proposal was made in Ohio to legislate at the State level a mandatory coal washing problem. The principal problem from the point of view of the utility industry and here the coal industry, that the large coal companies can aggregate and build facilities but this would pretty well drive out all of the small coal operators from that market.

Mr. Parker. The second question would be how much of AEP coals come from your western mines as opposed——

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[5] Larry Parker, Congressional Research Service, Library of Congress.

Mr. **Dowd**. We have one western mine in Utah. The coal from that mine is burned at only one plant, in three of the four units at that one plant. The coal is burned at our Tatters Street plant in southern Indiana, a plant owned by Indiana-Michigan Electric Co. It is units 1, 2 and 3. I believe that they are 135 megawatt units each. That is the only place where AEP captive western coal is burned on our system at the present time.

Mr. **Parker**. Another question. Most of the discussion here has been sulfur removal, but the bills also allow for NO_x removal and 2-to-1 ratio. Did AEP look at any NO_x removal and if you didn't, why not?

Mr. **Dowd**. The answer is quite directly no. We didn't. We may have given some very general consideration to it and rejected it as an alternative. It is on a 2-for-1 basis, it would involve substantial boiler modifications, very costly and we felt that since we are going to have to put scrubbers as we see it under these scenarios on the units or fuel switch that it was more cost effective overall to address the SO_2 issue and get the reductions there. But we gave brief consideration to NO_x.

Mr. **Parker**. Did you consider the fact that if you replaced an uncontrolled plant with a new one that meets new source performance standards there is a new source performance standards for NO_x too? So you would in fact receive some NO_x reduction that way?

Mr. **Dowd**. Now that you mentioned it I talked about replacing the lost capacity with new capacity, depending upon what the Mitchell bill really means, that new capacity will have emissions of its own. If those emissions have to be offset then we have to go around again. We recognize it as new capacity replaces old, it is better controlled, but in this instance the emissions from it as small as they may be are additional emissions on top of what we already had. We would have to find offsets. If our interpretation of the Mitchell bill langauge is correct, if we are wrong, we would like someone to stand up and say it definitively.

Mr. **Freeman**. On the substance point, I think this would be a good time to mention the major problem that we have which has been alluded to earlier by the fact that in many of these instances even if you weren't constrained by practical political considerations of what your State rate commission might do to you if you shift from local coal, you have the problem where you are free to substitute free of those pressures and usually you would be and the pressures would be the other way around where you don't have substantial high sulfur coal industry in the State.

That is, that fuel switching may be inhibitive because you would increase your particulate emissions. Even though that increase might still be within the SIP, if it is a substantial increase you will have subjected the whole plant to new source performance standards. That is a major problem. Indeed, it is a problem in our trying to, if economics continue to justify it, to substitute coal or mixtures for oil for existing oil-fired plants because you have got a slight increase in the particulate emissions. So you control the SO_2 emissions and you get a substantial reduction in NO_x emissions.

That may be a technical point that at some point you would want to address.

Mr. Moore. Why don't we press on at this point since we are consuming the time of the other folks. I would like to thank you for coming over.

Mr. Dowd. I am not trying to encourage it but if you think of other questions.

Pass them on to George. I don't think my people are going to enjoy my coming back. We will do the best we can.

Mr. Moore. Thank you very much.

Mr. Moore. Why don't we go on down the list as George has prepared it. That would mean that Dr. Charles H. Goodman, manager, air, water, and thermal sciences program of Southern Co. Services, Inc., would be next.

PRESENTATION OF CHARLES H. GOODMAN, MANAGER, AIR, WATER, AND THERMAL SCIENCES PROGRAM, SOUTHERN CO. SERVICES, INC.

Mr. Goodman. As you said, I work for Southern Co. Services. I represent the Southern Co., the Southern Electric System is represented by the majority of the coal-fired electric utility services in Georgia, those parts of Alabama not covered by TVA, the Panhandle of Florida and the southeast corner of the State of Mississippi.

Our system represents over 18,500 megawatts of coal-fired generating capacity, another approximately 2,500 megawatts of nuclear and 3,500 megawatts of others which is hydro and combustion turbines, meaning as of last year, our current generating capacity is something over 25,000 megawatts.

This system is spread over a good portion of the Southeast, consists of about 88 units, and as of last year we bought about 40 millions tons of coal to supply those coal-fired generating units.

Our system in the mine can basically be described as one of a moderate emitter of sulfur oxides in the sense that the order of the systemwide average would be less than 3 pounds per million Btu's. For the most part, like the State of Georgia has a SIP cap of 4 pounds per million Btu's. You are well under that. In fact, we are only one of those utilities where you get into talking about the actual versus allowable emissions we are probably 20 percent on the average below the allowable levels of emissions.

Mr. Moore. Are you including your hydro and nuclear?

Mr. Goodman. No; I am talking just coal-fired generating capacity. Using that capacity, those systems on the average are about 20 percent below the SIP's. Each State has its own SIP. Effectively that means we have somewhere between 1½ to 3 percent sulfur coal on our existing units, maybe even lower, being weighted down toward closer to the 1½-percent range.

My view or our view of the Mitchell bill really has to be described in a broader term of how we try to assess the dollars of what it would cost us trying not to get tied up in too many details, but saying if we get through from our mind conservative estimates, trying not to take into account things we don't know how to put costs on, what is it going to cost our customers? Basically, we looked at it in 3 to 4 parts. We looked at the assessment of the impact of a 10-million-ton rollback, our interpretation of that effectively was that they required on the average our emissions to be rolled back to about 1.2 pounds per million Btu's the 77 compliance coal levels on the average across all of our State systems.

The other part we looked at are the impacts of the NO_x-SO_x freeze which means controls on the future growth of emissions for our systems, the other parts of the nonutility boiler growth we may or may not have to do something about and there is the final issue you have discussed of the emission trading which I will make some comments on.

In general, talking just about the 10-million-ton roll back in 1981, we looked at it really two ways. The first we say we buy a substantial amount of 77 level compliance coal, 1.2 pound per million Btu's fuel. We have a unit in Alabama that uses local Alabama coal for that purpose, the plant Miller. We have a unit jointly owned by Gulf and Mississippi Power Companies, Plant Daniel, near Pascagoula, Miss., which uses low-sulfur Utah coal, and we have a startup of a plant in Georgia, which uses West Virginia, eastern Kentucky low-sulfur coal.

The analysis we made, say using those current provisions, no projections for disruption in the coal markets or whatever, using those prices, what would it take to blend, to use that fuel at all of our facilities to get our emissions down? That price came out on the order of $845 million additional expense. Putting that into rates to customers, it came to the 20- to 30-percent increase to the residential customers.

We then tried to address the scrubber issue. We feel we know an awful lot about scrubber, although we have not built them on new units. We have the largest pilot plant facility for testing second generation scrubbers at our Plant Schultz in the Gulf Power Co. system. It included analysis of forced oxidation limestone, dual alkaline systems. But to do the scrubber pricing we went back to the radiant study done by EPA that used the TVA data so that we would have some consistent base to talk to people about it.

Basically, what we said was about 50 percent of our capacity would have to be retrofitted with scrubbers to meet this same type of emission reduction. That represented a capital cost, although the money would be spent in the late 1980's in current 1981 dollars of about a $2½ billion expense. Then we looked at these bound, a total low-sulfur scenario versus basically trying to meet a good piece of the action with scrubbers.

Our basic assumptions, analysis, resulted in that that annual cost on the order of $800, $850-million-a-year increase in our rates due to the purchasing of increase in our rates would be about the same number. The problem is either way we don't know where we can get that kind of money. We are talking about the $2½ billion, our current construction program of about $1¼ billion a year is really stressing the company to say the least. Our financing is very difficult just to meet that need. Another impact of $2½ million would be, from our financial people's view, disastrous. We just would have to do something besides raise money.

The other number that might be useful is the current value of our system on the books is the order of $11 to $12 billion. So you are talking about a 20- to 30-percent capital increase if we went the scrubber route.

The NO_x-SO_x freeze at the 1980 level, we feel the general data illustrate a 10- to 20-percent growth over the next 10 years in electric utility generating capacity. For us it is not only that growth, but it is the fact that we are aggressively working to increase the utilization of our existing units through off-system sales so that we will have that capacity for our own system when we need it in future years.

We are into a construction program. Our current projected growth rate is in the order of 3 percent. Five years ago it was substantially higher than that and we committed to this construction program. The way that we—it would cost us more to cancel it than to continue it, besides the fact that we have a market for that generation over the next 10 years. We have major off-system sales contracts signed to offset the use of oil and natural gas in Florida, to offset the use of oil in Texas. Therefore, for our systems, the increased capacity factors and the growth of those new units say that we are going to have substantial emission increase just keeping it the way it is, measurable emission increases.

NO_x SO_x freeze again would be disastrous from our perspective. What does one do to get it back even if we are shooting at a target in 1990, because the costs would then even be greater than the numbers I just showed for the 10 million rollback. The question was asked earlier about NO_x. We have loked at NO_x to some degree. The problem is recalling the NSPS for NO_x, the new one is 6 pounds per million Btu's, the previous one in 1977 was 0.7. Our larger units, combustion engineering units are very close to those numbers already. It becomes a matter of what would one do to get any bang for the buck? The older units where you might get some, which may be closer to the nine-tenths or 1 pound per million Btu's, we have the great concerns about blowing up the boilers, corrosion, erosion, other types of problems. We have done some tests on our B. & W. boiler with EPA to try out low NO_x burners. They have not worked well at all.

The operating people do everything possible to get them out of there after we finish the test. We don't look at NO_x as being much bang for the buck. For us on a pound basis the NO_x represents about 25 percaent of our—what our SO_x number is. So we have got to have these massive reductions. We are not going to get much there anyway.

The nonutility boiler issue we just don't have much handle on that number. We know a lot of our potential customers, industrial, in fact, we have discussed getting into the business with them because of our historical experience of handling large amounts of coal, would like to convert to coal, but how much that is, whether or not we would have to make up the difference just exacerbates what we have talked about already.

Finally, this emission trading issue, our system operates on a system control system dispatch operation, based on economics. We were one of the first large systems to ever go to that, covering a four-State area as well as close interties with TVA and other large systems.

If the rollbacks on everbody are so great, our general view is the majority of the units will be the same emission rates. To start with, we are already pretty low. One, as Mr. Dowd says, it plays havoc with that economic dispatch type of system. We would have to build a new system to address the problem, but, two, we don't perceive that there is that much bang for the buck out there. If we are talking about the environmental problem, I guess the worst example, we don't perceive where we would be allowed to reduce our emissions to allow emissions to increase in the Midwest, upstate in the New England area. That is just not what we interpret as the problem that people say we are trying to address.

Finally, in summarizing what I have said, we haven't considered a lot of our factors that we think would double our numbers very easily. We haven't considered coal market disruptions because either way we think the optimum will say we will continue using moderate- and low-sulfur coals.

We haven't looked at the capital availability issue except to say it is not just one of these nice engineering economic studies where you talk about a few more percent increase in our expenses. You are talking about a 10- to 20-percent increase in capital related to what we currently value our system. Our financial people look at that as an impossible problem.

The "linearity" of the analyses of how you can come up with money we think goes down the tube. Where would one get that kind of money? We haven't looked at problems like electrostatic precipitator upgrades, the flue gas waste disposal problem. We just have plants like those in Mississippi, Florida, that are in marshy, estuarine areas. There is no way that we can talk about sludge disposal in those areas. Scrubber installations, those plants mostly built in the 1960's, which we expect to be around for an awful long time, were built right on the side of the river. The purpose being to submerge your condensers, no pumping head to pump the water up; once they are cooled there is no space.

The plant is within 50 feet of the water line. The crudeness and the difficulty of putting in scrubbers is going to be a major chore, especially on those older units. Replacement power costs was brought up. We really didn't harp on that a lot. Obviously it becomes some number, whether it is 3, 5 percent, it is still going to be more dollars on it. The availability issue, our view on new plants is the availability is something we can work with. But these existing plants with these complex engineering problems we don't really know how to address that problem unless we get into detailed engineering studies which we haven't done.

I think the bottom line for us is still we just see no benefit for being down in the Southeast, having to do these kinds of controls to address the problems that we don't really think are well defined in upstate New York and Canada. We are an awful long way from those people.

We believe in long-range transport, but we also believe there is a lot of things closer to problems and the problems better be well defined.

In general, I am trying to look at the list here to say, age, capacity factors, those kinds of things were brought up.

Our general view is we are not going to retire units until they darned near fall down because our old units are cheap generating costs when you are talking about office system sales and those groups we sell energy to, who are on oil and natural gas.

It just isn't in our estimates to have cancellations of units. We have got 20-megawatt units that have been on the retirement list for 20 years. But they are still there. Maybe the cost of upgrading precipitators might do away with some small ones.

I think the bottom line still is for us we keep looking at the environmental issue which is not the forum for us to talk about, but I would like to say that our view is if you look, it is a societal problem, it is a total pollutant loading to the atmosphere that one is going to address, if you find the problem relating to that. Not knowing what this forum was totally about when I was told to come up here 1½ days ago, I did bring some charts rereduced from OTA data, trying to show that if you took the land area of several New England States or that part of the country, spread it out instead of doing it by a State-by-State basis, calculate the total emissions, not just from utilities, but from industrial, and residential and for NO_x and SO_x., then you start getting the same levels of emissions that you get from Midwestern States and much greater than what you get from some of the States in our area.

The way this is reduced off the OTA data is to take the emissions by State for various categories and divide it by the area of the State. But the bottom line is still the same.

I could have accumulated regional groups of States of similar size and I would have showed you basically that they are very similar. So long-range transport may be an important problem, but our view is that the stuff sitting close to whatever your problem is, is critical, too.

Mr. **Moore**. I just feel compelled to say on behalf of the chairman of the committee who is from Vermont that the sulfur emissions from the wood-fired utility in Vermont are not very high.

Mr. **Goodman**. I think the chart shows me Vermont and Maine have got some problems, they are right. Their State levels are not that bad. But I think the problem we perceive, like New York State——

Mr. **Moore**. If some of the rest continue to die at the rate they are now, we will have a lot of wood to burn to generate electricity.

Mr. **Goodman**. Yes; then we can worry about the carcinogens and other things that come from woodburning. I think the bottom line for us still is—I will move back more to the States that I know how to talk about, that what is the bang for the buck for an $850 billion bill because I assure you the citizens of Atlanta, Birmingham, Ala., is one of those top five States in unemployment right now, that those citizens can find an awful lot better things to do with that money.

Mr. **Moore**. Forgive me if I mispronounce your name, Mr. Ali, who is manager of environmental programs, Public Service Indiana.

PRESENTATION OF SY A. ALI, MANAGER, ENVIRONMENTAL PROGRAMS, PUBLIC SERVICE INDIANA

Mr. **Ali**. Thank you for this opportunity. I am accompanied by James Pennington, vice president of financal operations.

Public Service Indiana is an investor-owned utility with about 60,000 stockholders and serving about 540,000 residential, farm, school, business, and industrial customers. Its service area includes 69 of Indiana's 92 counties and covers approximately two-thirds of the State's geographic area. The company's 1981 revenue was $720 million with nearly a third of the sales to industries in its area. PSI operates six coal-fired stations totaling 5512 megawatts.

The actual SO_2 emissions in 1980 on the new stations were about 40 percent of the currently allowable emissions.

An analysis of the cost impact of the Mitchell bill—S. 1706—on PSI customers was conducted in mid-1981. PSI's interpretation of the bill was that 85–90-percent removal of sulfur dioxide would be required to achieve the company's share of the reduction required in Indiana.

It does not offset new source emissions added since December 1980, which would be required to offset existing sources. It assumes that Indiana Air Pollution Control Board would expect all SO_2 reductions should come from the major utility sources.

Our projected reductions would correspond closely to the scenarios we have been discussing, 8.1 million tons. These reductions would bring PSI's SO_2 emissions, from existing sources to below 1.0 pounds per million Btu, and below indicated emission levels of several Northeastern utilities.

Several alternative technologies for sulfur dioxide reduction were considered. Low-sulfur coal at baseload stations was more expensive than scrubbers based on cost projections provided by our coal suppliers. Coal washing would only provide a small additional reduction of sulfur dioxide since Public Service Indiana is already burning over 75 percent washed coal. Scrubbers were determined to be the least costly method of making the required SO_2 reductions at the company's four baseload stations—5,272 MW total—and converting to low-sulfur coal was the least costly method at the coal-fired peaking stations—240 MW total.

NO_x controls are not considered because of the operational risks with the boilers by imposing such controls. NO_x controls would present reliability reduction and potential boiler damage risks.

Total capital cost for scrubber equipment, installation, and sludge handling equipment were estimated at $1 billion to $1.4 billion—1981 dollars. Our cost estimates are based on our current engineering estimates on a flue gas desulfurization [FGD] system at our Gibson station, and are comparable with other estimates by utility industry and the U.S. EPA.

Interest rates, and availability of construction funds for the industry, influence capital charge rates associated with such projects. Our current capital charge rate is in excess of 22 percent per year. These fixed charges consist of recovery of the capital investment, interest on the capital, insurance, and property taxes.

These charges are recognized and used by the Public Service Commission of Indiana in setting rates.

The annualized cost, which consist of annualized capital and operation and maintenance costs, is about $400 million. The operation and maintenance expense of 5 mills per kilowatt-hour also includes an allowance for additional capital investment to replace the power consumed by the FGD system, estimated at 8–9 percent for retrofit systems.

I would like to emphasize here that all of these above cost estimates do not represent the worst case scenarios but are based on the minimum cost impacts.

These costs indicate that the passage of the proposed legislation would result in about a 50-percent increase in the amount paid by our customers for the electricity they use. For the average residential customer this would increase his cost by over $230 per year or almost $20 per month. Commercial and industrial customers will pay substantially larger amounts which will create further inflationary and job curtailment pressures.

The billion-dollar-plus investment—1981 dollars—required to meet the terms of the Mitchell bill will not add to the productivity of PSI. If the investment were applied to new conventional coal-fired generation—with scrubbers—the company could build a 700- to 1,000-MW unit. This would support economic growth equal to a new community the size of Fort Wayne and Terre Haute combined, or an urban population of about 247,000.

It is important that we carefully evaluate and justify these massive investments in sulfur dioxide control. According to Dr. Volker Mohnen of the State University of New York, even with such drastic control measures imposed in the Midwest, the acidity of rain in the Northeast may not be reduced appreciably.

Thank you very much.

Mr. **Moore**. Thank you.

Next would be Mr. James H. Pennington, vice president, financial operations, Public Service Indiana.

PRESENTATION OF JAMES H. PENNINGTON, VICE PRESIDENT, FINANCIAL OPERATIONS, PUBLIC SERVICE INDIANA

Mr. **Pennington**. Speaking strictly from a financial standpoint, my company, Public Service Indiana, is already facing severe capital-raising problems. We are engaged in a capacity expansion program centered around the addition of a coal-fired unit with scrubbers—$425 million—and 2 nuclear units estimated to cost $4.3 billion. PSI will own 83 percent of the nuclear project. With the above-named projects and other required capital expenditures, Public Service Co. of Indiana has capital expenditure programs approximating $2.5 billion in the 1982–85 period and $1.5 billion in the 1986–90 period. Under the proposed acid rain legislation an additional $1.0 billion to $1.4 billion based on 1981 costs would be added to this already ambitious program.

I submit that it cannot be accomplished. PSI has already experienced one credit downrationg and is likely to experience another. With the additional financing burden under the proposed legislation there is little doubt that additional downratings would result.

During the next several years there will be times PSI will not be able to issue first mortgage bonds due to lack of coverage—earnings times interest cost. By selling debentures, this further increases the cost of borrowing money to finance construction.

In Indiana, projects under construction are not allowed in rate base. Although efforts are being made to change this through proposed legislation, nothing is guaranteed. Financing costs will exceed over 40 percent of the nuclear project. Internal cash generation is almost nonexistent. Almost all construction expenditures must be financed by outside new capital.

By adding the need to finance $1 billion or more of additional capital expenditures during this timeframe is close to being the straw that breaks the camel's back. I am citing only the case of PSI. Many other utilities are in the same position.

The additional capital costs must ultimately be added to the cost of serving customers. Based on today's cost (1981) this will add up to 3 cents per kWh compared to 1981 costs of 5 cents per kWh. These increased costs will have severe impacts upon our customers and the economy.

Mr. **Moore**. Are you saying that the $1 to $1.4 billion which you assigned to S. 1706, that alone would add 3 cents per kilowatthour?

Mr. **Pennington**. Yes. I am.

Mr. **Moore**. Would you provide for the record the cost per kilowatthour which is being added by the cost of financing the nuclear projects and the coal-fired scrubber plant as well?

Mr. **Pennington**. I can provide the projections. Those are future things to happen.

Mr. **Moore**. Yes; it puts it in the same category as S. 1706. Right?

Mr. **Pennington**. There are many other practical considerations that have not been addressed. Some of these are manufacturers' ability to provide and service equipment, finding and training the large numbers of operating and maintenance personnel and the problems of collecting and storage of waste products. Operation of flue-gas scrubbers has been anything but reliable although some improvement has occurred. However, if every generating unit has a scrubber, without a doubt, greater reserve capacity would be required necessitating the building of additional generating capacity. This also adds to the cost of providing service with the possibility of further disrupting the economy.

The perceived problem of acid rain has substantial adverse economic implications if ill-though-out legislation is passed without facts to support it. The proposed cure may be more harmful than the perceived problem.

Mr. **Moore**. Thank you. I was surprised at that cost of capital. What is the average rate at your company right now? I shouldn't interrupt, I guess.

Mr. **Pennington**. Cost per kilowatt-hour to the residential customer is 5 cents.

Mr. **Moore**. Will you provide for the record the impact of borrowing, of the financing of the $4 billion capital expenditure programs that you have underway for the 1962 to 1990 periods as well.

Thank you. The next spokesperson will be Mr. Robert McKnight, chief environmental engineer with Indianapolis Power & Light Co.

PRESENTATION OF ROBERT McKNIGHT, CHIEF ENVIRONMENTAL ENGINEER, INDIANAPOLIS POWER & LIGHT CO.

Mr. **McKnight**. Excuse me. This morning I had some slides prepared so that what I had, when I found out you didn't have a vugraph, there are copies of that. So there is a lot of error in those pieces of paper I handed you.

The first page on that, and I will dispense with a lot of it, investor-owned utility, we operate in central Indiana, we burn virtually 100 percent Indiana medium sulfur content coal.

Unlike some of the other projects around that you have heard today all of my dollars, unless I state otherwise, are in terms of 1990 dollars, cost projections made on 1981 dollars when we made this estimate were escalated to 1990, assuming that, one, we could not build FGD systems much faster than before 1990 in any case so that we would be talking in actuality 1990 dollars. These have been compared by the company to 1990 projected revenues.

The first page of the handout I had, basically describes our systems which would have two NSPS units, new source performance standards units.

One of them is in service now. One of them is under construction. We assumed that these would not be affected further by the Mitchell proposal. We would also have to backfit two units. We looked at our system basically on an economic basis saying units less than 400 megawatts would not be economical for us to go back and try to install FGD systems on it.

Part of this is related to side specific constraints which I can get into in a second.

Fifteen boilers would convert to low sulfur coal, would be out-of-State, out of our coal region and type coal. These are all smaller units.

If you divide these 15 units into the capability you are going to come up with something like 51 megawatts. We don't have a 51-megawatt unit anyplace. But that is about the average size. They range from 200 down to things as small as 20 megawatts. We have 11 oil-fired units with the capacity shown there, we would anticipate no changes in that and a few diesel units.

The next overlay that I had is the capital cost requirements. Item I on that is $400 million and that is to backfit these two 400-plus megawatt units.

I will go into the detail on that in a minute.

Item 2 is approximately $100 million for upgrading of the particular control on the 15 boilers. That would go to low sulfur coal and item 3 which is $480 million is basically our replacement costs for the capacity we lose in installing scrubbers and installing or in burning low sulfur coal.

To look at these annualized costs, annualizing the total $989 million capital cost, we come up with $237 million annual fixed charges, our various operation and maintenance costs of the flue gas control systems, the additional cost of the out of region coal, we totaled $356 million.

Those are in terms of 1990 dollars. Those were taking place basically from 1981 estimates and unless I specify otherwise, were escalated at 10 percent simple interest per year.

When we compare to our 1990 revenues, these costs accumulate to approximately 49-percent increase in revenue requirements over other revenue requirement increases that we would anticipate across that time.

The FGD systems, the first one that we would put in would be on our EW stout unit No. 7, which is a 440,000 kilowatt hour unit, constructed in 1972. It would be burning around a million tons a year of Indiana coal.

The constraints, this station sets—it is within the interstate loop in the city of Indianapolis. We have some severe constraints on space and FGD sludge storage.

We are surrounded by some other industry that has some badly contaminated ground waters and the consequence this is that there is a very high sensitivity to strong sludge or any other material in this area.

We would expect some major problems, some major cost increases for protection of the ground waters in this area.

This, like most of the other units built in that day are backed up against the river and we would expect some significant cost increases for handling or because of the space constraints.

In addition, this plant has no other flue gas desulfurization systems. It has no limestone handling systems. This station would also in this case be burning a combination of two different coals, so we would have to revamp the coal handling system.

We would have to add a limestone or lime handling system as pretty significant costs because you are shoehorning them into existing equipment.

From the one FGD systems that we have in service right now, the controls and electrical controls for switching for an FGD system, on our present system, take a three-story building, about 60 feet tall, 70 feet by 50 feet. So just even a building for the controls of it, that doesn't include the FGD system at all, is a sizable type building.

The second unit we would install the FGD systems on would be the 455 megawatt Petersburg unit 2. This is the station where we already have one FGD system in operation.

The unit came into operation in 1969. It will burn in excess of 1.3 million tons of Indiana coal a year.

We have severe space constraints on this. It is backed up against the FGD system on our unit 3, on one side that system ran in excess of $60 million and since it went into service in 1977, we have put into another $10 million to $12 million worth of modifications attempting to make this work.

It has, in fact, this week is undergoing acceptance testing on a $26 million particular control system just added to this which would set right in the area where we would have to be building the FGD systems. So we would either end up building duct work that would be something in the range of 49 feet wide by 12 feet tall or duct maybe as big as this wall behind me in cross section to 200 or 300 yards to another area or tearing down this $26 million particulate control piece of equipment to shoehorn an FGD system in on this.

The particulate control system was recently upgraded on our unit 2 at another $6.5 million. That boxes in the remaining side along the river.

So that we have again for units that were built prior to the advent of NGD systems a severe pace problem. Part of this would probably have to be on stiff legs over the river to get it out around and back to some area we could fill it.

We would also use up our disposal site which we presumed we could get permits to extend it without major other construction efforts. But we would consume the sludge disposal area for our units 3 and 4 which are in the NSPS units which would also be disposing of sludge in the area.

We did not consider that after the cost inlay.

The next major cost is, on the next sheet that I have, and it is anticipated costs in the fuel changes on the 15 boilers. These boilers burn as an aggregate about 1.6 million to 2 million tons of coal a year. This would have to come from our region, either from the Far West or from the East.

Our estimates were based upon companies because we took somewhat less penalty in capacity reduction. We have hauled in coal from both the West and the East and our capactiy reductions on these units would be in the range of 25 percent.

This 25-percent reduction is reflected in very high cost of replacing this capacity. In addition, we assumed a 5-percent reduction in capacity on the units we backfitted with FGD systems.

The nature of the particulate control systems on these units would not accommodate the low-sulfur coals. The capacity loss is basically, if we go to eastern coal, much harder to grind.

There isn't much we can do to modify the system. So we just couldn't grind enough coal to put it in the boiler to maintain our current capacity.

In addition we would have to make major investments in particulate controls.

If we were forced to do this out of region coal, we would also have to make major investments in railroad stock because railroad cars are just not available to haul this type of tonnage of coal. We would be talking about 20,000 railroad cars of coal a year that we would have to shift.

So we might also have to make investments in some preliminary discussions with rail companies. They want you to buy not only the railroad cars but the power units to pull them as well. So we might be getting into the railroad business.

One of the major considerations of our fuel people in these test drills where we brought coal back, we brought 40 cars from the Powder River basin in Wyoming. We sent 40 of our cars out there to haul the coal back. We got 28 of them back in one group, the remainder straggled in over the next month. This was not under any severe weather or other severe things.

So that we can see that we would have to have higher inventories of coal to maintain a reliability.

During the coal strike, I believe in 1978, we had some eastern coal come in and it took us a month to thaw it.

When we put it in our thaw sheds that we use for local Indiana coals, these are in essence giant electric cookers, Indiana coal freezes to the outside of the car. Once you break that ice, it will slide out the bottom. The eastern coal that we brought in, we had 100-ton block of coal frozen solid. It took us over a month to get this and it was basically a weather change that thawed this out.

You cannot put in more thawing. In fact we burnt up one car trying to thaw it out. So you have got some practical problems of shipping coal long distances, particularly under adverse weather conditions that almost defy description.

I think in my thing I talked about the difference, side differential on these units. Our estimated cost would be $30 a ton. That is present day delivered cost. That escalates to, that differential, to about $57 a ton differential for low-sulfur coal by 1990 which this is the point where the impact is really being felt. That was the assumption use, a $57 a ton premium.

We really don't know how to throw in the extra cost of handling this out of State coal when it is frozen harder and so forth. Our fuel people say that if the Mitchell bill were to be promulgated we would have significantly more pressure on the low-sulphur coal markets and they feel like this cost differential is probably well on the low side. It would end up being significantly more.

For replacement capacity, we used our engineer's estimate on our unit that will come in to service in 1990. The capacity loss on these other units would be made up out of the capacity on that unit. Obviously some future unit has to come in service sooner as our load grows. Our engineer's estimate on this in 1990 dollars is $1,719 a kilowatt. That was used to cost out the cost of the capacity loss. We have no retirements. I have got units that were built in 1931, 50 years old. We still have them there. We still fire them up when we get on peak. They are inefficient units. But for the high cost of new capacity, we can afford to run those for the short duration.

So we did not cost out or add to our costs by retiring units early.

The precipitate or backfitting costs are based upon as I said before a precipitator that we are putting into service this month. We are running an acceptance test tomorrow. Strictly proportioned on a kilowatt basis, on these smaller units that is probably a very conservative systematic since the unit we installed was a 450 megawatt unit, approximately 26 million tons for the FGD system on that unit. We would be installing a lot of small electrostatic precipitators on units that are constrained on space substantially more. So the cost would in essence be higher.

Those costs will consider backfit as well, were escalated to 1990 since it appears to us unlikely. We can't snap our finger and say automatically we would install these.

For our rate projection, we compared those to 1990 projected revenues. The bottom line was a $356 million per year annual cost. That is a 49-percent increase over the projected. Our gross revenues for last year, everything paid to the lifetime, was approximately $316 million. So if you compare it to current revenues it would well more than double our electric rates. But I think you recognize that is not probably an appropriate comparison, or only in terms of the total dollars that would have to come in for this would be greater than the company's total revenue at the present time.

Mr. Moore. Thank you.

Mr. Charles V. Runyon, manager, Environmental Special Projects Department, Ohio Edison.

PRESENTATION OF CHARLES V. RUNYON, MANAGER, ENVIRONMENTAL SPECIAL PROJECTS DEPARTMENT, OHIO EDISON

Mr. RUNYON. As you introduced me, my name is Charles Runyon, I am manager of the Environmental Special Projects Department of Ohio Edison in Akron, Ohio. The cost and difficulties of environmental compliance are issues of daily importance to me. Our greatest concern is the possibility of further SO_2 reductions in the name of acid rain.

The recent moves in the U.S. Senate, particularly bills sponsored by Mitchell and Moynihan threaten our consumers with enormous increased electric bills without reasonable assurance of measurable environmental gains. We should remember that SO_2 emissions have already been substantially reduced in Ohio and in our particular case about 22-percent reduction occurred between 1978 and 1980. We figure that this and other strategies were undertaken for clean air compliance will increase electric bills by 15 to 20 percent.

In an attempt to get a handle on just what the costs might be we looked to our own experience. We operate the largest flue gas desulfurization system in the world at the Bruce Mansfield plant at Shippingport, Pa. The total cost of the plant was $1.3 billion of which over $400 million was invested in flue gas scrubbing systems. Approximately 30 percent of the total investment, and it is generally less cost effective to retrofit scrubbers on an older smaller plant. Should we be required to retrofit all our older plants with scrubbers it would be a very expensive proposition.

Retrofitting our older plants could run in the magnitude of $1.5 billion and require increased revenue somewhere in the area of $430 million a year. The result of the average residential customer's electric bill would be increased about 40 percent.

Our estimate of a 40 percent rate increase was derived in this manner. We started with an exhaustive analysis of compliance options and related costs prepared for us in 1977 by Gilbert Commonwealth Associates, a nationally recognized engineering consulting firm. The scrubber option which we believe would be necessary to comply with the Mitchell bill totaled $1.5 billion in capital costs. We then estimated the operating and maintenance costs for each plant based on the actual experience with the scrubbers at our Bruce Mansfield plant. Our rate people then translated this cost into annual revenue allowed under Ohio ratemaking law. So our total of about $430 million a year represent the combined provision of capital and additional operating and maintenance expenses. $430 million divided by current annual revenue of slightly more than $1 billion equals approximately 40 percent.

That is the kind of numbers we think we are looking at if Senator Mitchell's bill passes, about 70 percent or more reduction in SO_2 emission.

The Mitchell bill also mentions various strategies to reduce SO_2 emissions, including coal cleaning and switching to a lower sulfur fuel but to an important degree the benefit of these options have already been consumed. In Ohio Edison's case, more than half of the coal we burn is already washed and the balance is largely low- and medium-sulfur coal with which washing provides minimal benefits in terms of reducing total emissions.

As for the low sulfur coal options, we don't believe anyone can meaningfully estimate the implications of massive additional shifts to low sulfur coal.

There are simply too many unknowns related to reserves, transportation, costs that would result from competitive forces, equiment tolerances and importantly, whether such coal would allow continued compliance with the particulate regulation using existing dust collectors.

We agree absolutely with the massive research that currently is underway, that will tell us whether some pattern of emission reduction will yield a significant benefit.

I hope sincerely that we as a Nation can choose a course of objectivity and plain commonsense. If we are not very careful, we would figuratively be burning money where we should be burning coal. And that basically concludes my written presentation.

In closing I would like to make just a few remarks. I heard some questions that were asked of Mr. Dowd and I would like to extend an invitation right now to any of you people that are listening to me to come visit us at our Bruce Mansfield Plant and see a plant that is fully equipped with scrubbing devices. I think it would help you all to understand the concerns that we have today, maybe some of you have seen these.

Second, we are retrofitting a dust collector which is the largest retrofit system ever attempted in one of our plants. It is the W. H. Sam Plant just north of Steubenville. The estimated cost is $450 million. I think it represents a great example of what problems you run into in retrofitting something. We have constructed a 920-foot deck over top of a two-lane highway which now the dust collection equipment is being constructed on. The reason for this is because there isn't any space to put it anyplace else.

I know some of the questions that were directed to Joe about costs that PEPCO, ICF, many of the studies have made relative to the cost of installing and retrofitting equipment. I think this is an example and it is a picture, if you see it, of how costly a retrofit system can become. We again entertain and would welcome anyone to take a look at these two construction projects that we have completed, the one in the process and the other. I think it gives you a good perspective of what kind of complicated problems we are facing today.

One other thing I would like to say. I personally have mis—I am very much involved in the acid rain problems, like acidity problems today. I have spent 24 years working in powerplants, working on water chemistry, working on water engineering. I would just like to say that every time I hear someone talking about a low pH or a pH or a pH reading and tie it to an acid condition of rain, I wonder if anyone realizes that most of the data as I see it on pH data is next to useless that we are looking at to base some of our conclusions on, that these terrible things are happening.

You know just the other day I sat down and calculated how much acid was in a 1 inch or in 1 inch of rainfall on an acre that would occur in Ohio and I took some of my, I have a rain monitor. I took a sample. I analyzed it and calculated, did my theoretical calculations and compared it to the actual analysis of the water. This sort of bore out the study that was done at the Connecticut

Agricultural Station. There was in a sample of water that had a pH of four, it calculates that in an average rainfall in Ohio of about 35½ inches, you would accumulate about 40 pounds of acid. Just think of that. That is hardly a drop in a bucket. So some times I wonder what we are even doing here, why we are looking at some of the issues that we are looking at today.

Mr. **Moore**. We did have two days of technical inquiries with biologists and atmospheric chemists and meteorologists on that subject. I think we will go on to Mr. Smith. However, I would like, so I don't forget it, would you please state, and provide for the record your cost estimates. You said they are based on the Bruce Mansfield Plant. I note that it has an emissions rate of four-tenths of a pound per million Btu. I trust you are not suggesting that all of your plants would have to reduce to that level. So if you could state specifically for the record what level you think your plants would have to reach and the relevance, if you have used an estimate of four-tenths of a pound per million Btu—that must be a plant in extraordinary circumstances—please indicate whether you think those kinds of costs are relevant to the controls you would have to impose under S. 1706.

Mr. **Runyon**. Yes. First, the Bruce Mansfield emission limits are six-tenths of a pound per million Btu.

Mr. **Moore**. Just for the record would be fine.

Mr. **Runyon**. Six-tenths of a pound per million Btu.

Mr. **Moore**. My figures indicate that the actual emission rate is four-tenths.

Mr. **Runyon**. That is the SIP.

Mr. **Moore**. If you would indicate for the record.

Mr. **Runyon**. Fine. When you install scrubbers and usually the most common type of scrubbers today are the wet lime or wet limestone scrubbers, your cost differential between 90-percent removal, 80-percent removal is very small. So really when we look at the Bruce Mansfield Plant we are looking at above 90-percent removal. I think that would pretty well represent the percentage removal that we would have to look at based on a coal sulfur content. That runs in the area of 3 percent.

Mr. **Moore**. If you could provide for the record for each of the plants in your system, how that plant would comply, scrubbing or fuel switching and if compliance would be through scrubbing, indicate the percentage of removal you think it would have to achieve, the cost of the scrubber and that sort of thing.

Mr. **Pfifferland**. Did R. Runyon have a handout?

Mr. **Moore**. Did you have a written statement?

Mr. **Runyon**. Yes. I am going to give it to you.

Mr. **Pfifferland**. There were a lot of numbers in there if we could get copies of it.

Mr. **Moore**. Next, Mr. Jerrel Smith, manager of environmental affairs, Union Electric Co.

PRESENTATION OF JERREL SMITH, MANAGER, ENVIRONMENTAL AFFAIRS, UNION ELECTRIC CO., ACCOMPANIED BY JOE BIRK, ASSISTANT TO THE CHIEF EXECUTIVE OFFICER

Mr. **Smith**. Thank you.

I would like to introduce Joe Birk, assistant to our chief executive officer and legislative affairs and other matters. I would just ask Joe at the end if I miss something that may be important to you, he might point that out to you.

I have a prepared calculation sheet that I would give you. I will just briefly summarize what is in it so that you might have an opportunity to ask questions if you wish.

The analyses that I am going to give you was asked for by the Office of Senator Danforth. So it was produced for that purpose but I think will satisfy your needs as well.

Generally, the Union Electric system serves the major metropolitan St. Louis area plus out toward the central part of the State. We serve a portion of Illinois and Iowa as well. We have three hydro plants of about 650 megawatts of capacity, two oil-fired plants of about 550 megawatts and four major coal-fired plants of about 5,600 megawatts.

Since the emissions from the oil-fired plants are insignificant there was no attempt to try to include an analysis of those emissions in this paper that I intended to give you.

We did or I did our analyses on S. 1706 soon after it was introduced and used data available at that time which I have identified in my paper. New data that has now become available would indicate that the emissions reduction in the State of Missouri would be considerably higher, requirement would be considerably higher than the tonnage calculations you find in my paper. I concluded that we would have to reduce our emissions in our system by about 68 percent based on the new number, it would be more like 85 to 87 percent. Therefore my analyses is on a much lower tonnage reduction basis.

Missouri's share of the emission reduction as I calculated it, with that original data, was about 7½ percent of the 31 State region. Union Electric's portion or the percentage reduction in the Union Electric system was computed to be about 37 to 40 percent of that in the State of Missouri and Union Electric Co., burns about half of the coal in the utility powerplants in the State of Missouri.

I looked at the four coal-fired powerplants and determined that for the purpose of this analysis we would choose to backfit two of the larger plants with scrubbers and use low sulfur fuel in the other two plants for reasons which I have set out in my paper.

And in addition to put aside any concerns of those who would choose to quarrel with either one or the other option, I think clearly the material that I submit will tell you what my logic was in choosing this method of compliance for this purpose of analysis.

I would have to say immediately that the $200 million annually and the 20-percent increase in revenue needs is very low. We could not achieve these reductions at that cost. The cost would be substantially higher for reasons that I will try to point out and I think will become obvious to you in the paper.

The scrubber studies that I used to support the analysis on scrubber costs were done by engineering firms in early 1978 and they expand the years of installations, 1979 to 1984. So the cost numbers are barely current numbers. We would be backfitting in this case 3,400 megawatts of capacity at a cost of about $715 million.

The total annual cost as I have indicated for compliance, low-sulfur coal and the scrubber option, would be about $200 million a year. However, the scrubber option was based on such numbers as the following. Thirteen percent fixed charge rate. I am sure you all know that is more in the range of 17 to 20 percent today. Therefore, we could not install scrubbers for that price.

The capacity demand charge used in that study was $590 a kilowatt. I think you are more in the range of $1,000 to $1,100 today. The engineering studies would have required removal of 90 percent of the SO_2 in that portion of the gas scrubbed. The design would have scrubbed about 75 percent of the gas with the remaining going for reading. The fact is 90 percent on that scrubbed would not reduce one plant's emissions sufficient to achieve what we have to achieve. So at least that plant would have to have more scrubber capacity on it than this analysis was based on.

I did not take into account the fact that in the State of Missouri we cannot carry into our rates construction in progress, as well as the fact that we cannot carry fuel changes into our rates automatically. We have no adjustable cost.

There was some talk about availability. I did not include in my cost estimates the replacement capacity that would result from the increased unavailability of the generating units. If my arithmetic is right, we asssume that a boiler turbine system would generally have an 85-percent availability, and added a scrubber that has 95-percent availability, you would lose about 4 percent or so of your generating capacity, the combined probability of failure would result in about 4- to 5-percent loss of capacity.

I did not compute and include the cost of that lost power which would run another $135 million perhaps. So I only point those out for your benefit. My cost analyses were done on the data available with solid supportable but we cannot accomplish what would be necessary at these costs.

We did not include the cost of the additional rail cars as others have spoken about here. I would be happy to provide you with additional information if you wished to call us, but I would like to point out that from my point of view, in any of these environmental legislation, particularly the air laws, that you consider seriously the question of carrying into your rate base immediately any investment in the environmental control equipment because financing problems I think as you know in this business are significant.

In addition, I think that the purchase of lower sulfur fuels and the cost of that ought to be automatically passed on in the rates if we are going to face those enormous problems of increasing rates.

I also think that you might want to consider the question of availability of scrubbers. You can build a scrubber. I happen to be fortunate or unfortunate as you might want to view it to be associated with the installation and start up of the first scrubber in the United States. We built that for about $20 or $25 a kilowatt, but it only ran 120 days. Today, we ought to build that scrubber for 65. You simply have got to look at the cost to see what it takes in bucks to get you an available system that is going to perform for you.

There is some very tough penalties in the air law. We have to comply 100 percent of the time, not 95. I really don't think in this equipment development period that the owner ought to suffer all of those penalties or the risk of those penalties until that equipment is demonstrated. I would suggest that you might want to consider that the owner not assume those penalties until that equipment has been demonstrated to operate successfully in compliance.

Joe, do you have anything further?

Mr. BIRK. No.

Mr. MOORE. Would you indicate for the record why scrubbing would be your choice for compliance as opposed to fuel switching and at Rush Island and Merrimack which already have fairly low-emission rates, you apparently would bring them down even lower by fuel switching. If you would indicate for the record what kind of fuel you are using there, and why you would use fuel switching there.

I don't mean right now. I use this term of art for the record and forget that you may not know what I mean.

Mr. SMITH. I think you may find answers to those questions in this paper.

Mr. MOORE. Thank you very much.

Mr. Jack Kaslow, senior vice president, New England Electric system.

PRESENTATION OF JACK KASLOW, SENIOR VICE PRESIDENT, NEW ENGLAND ELECTRIC SYSTEM

Mr. KASLOW. Thank you. I will try to be very brief.

Ms. PFIFFERLING. Could I make a point?

If you have a handout, could we get it prior to your discussion as opposed to after?

Mr. KASLOW. It is just an outline. Our problems in New England are a bit different from other parts of the country with respect to the Mitchell bill. And I would just like to touch upon briefly what the principal parts are. Utilities in Massachusetts and Connecticut decided early to try to look at the impacts of the Mitchell bill upon our operations and we found that between utilities and among, I should say among utilities and between the two States the problems were quite different.

The outfall of our review was that the major impact would be fewer coal conversions in the region if the Mitchell bill were passed, more oil would be burned and the oil that was burned would be a lower sulfur and more expensive oil. These lead to the cost impacts which I have shown on the sheet just handed out that would affect my own company which would not have to abondon any coal conversions but which would be forced from a 2.2-percent sulfur oil in some generating unit gradually down to a 3.0-sulfur oil resulting in penalties resulting in about $30 million a year.

Larger impacts would be felt by Boston Edison Co. which believes that they would have to abort some planned coal conversions. Their costs are substantially higher.

Northeast Utilities in Connecticut has a unique problem in that even though Connecticut would have no rollback requirement under the Mitchell bill, the imposition of the cap would preclude coal conversions of units in that State. Since their current emission limit is 0.55 pounds per million Btu's, they feel it would be impossible to convert under those conditions.

One might ask if it wouldn't be possible to undertake these conversations and install scrubbers. The problem is that most of these plants, all the plants are in congested areas and space requirements become a very compelling problem. We have seen that in our own coal conversions where we simply had to have precipitators and no scrubbers, where there was a need to add scrubbers, we just couldn't have it in some locations.

That is the problem with Northeast Utilities plants and especially with Boston Edison where their generating plants are located in downtown Boston, right along the harbor, physically impossible to do that sort of thing.

Again, I would just reiterate that even though our rollback requirements in Massachusetts and Connecticut are normal compared to many parts of the country, there are indeed cost impacts and aside from the cost impact of the security concerns we have, with our continued dependence on residual oil and the fact that some of our coal conversions just wouldn't take place.

If you have any questions, I would be happy to go into details on those points.

Mr. **Moore**. Thank you, very much.

Mr. **Freeman**. We don't have Curt Anderson on the list but he is here.

Mr. **Moore**. Mr. Curt Anderson, New York Power Pool, did you have anything in writing?

PRESENTATION OF CURT ANDERSON, NEW YORK POWER POOL

Mr. **Anderson**. Yes. I have a very short summary. It outlines the major points, also a short overview on the future plans of the electric companies in the State of New York.

First, by way of introduction, I represent all the seven investor-owned companies plus the power authority of the State of New York here today.

The State has slightly over 30,000 megawatts of installed generating capacity. The nice part about it is we are 59-percent oil-fired. We have about 2,550 megawatts of coal-fired capacity. The rest is made up of hydro and nuclear.

1706 has three major cost implications for the New York companies.

First of all our emissions as of today are very low on a system of 30,000 megawatts. We put out less than a half a million tons of SO_2 per year as of 1980. The major impacts as we see the bill would require that all our coal-burning facilities in the State which are located in the northern and western part of the State would have to retrofit scrubbers. There has been a fair amount of discussion today about the use of low-sulfur fuels in place of scrubbers.

Yes, while that may be physically capable, the cost implications are completely unknown with the thrust of such a bill. I would expect that the low-sulfur Eastern coals and we must use Eastern coals because of the design of these plants, probably the cost of that coal would tend to equilibrate somewhat with the cost of scrubbers.

We have estimated the scrubbers for retrofits and maybe compared to some of the fellows around the table this morning, have said the number is higher than what we have estimated, but somewhere in the order of $450 per kilowatt and when you crank those numbers through, the costs are in the order of $600 million up to over $1 billion in capital costs.

When you annualize that, depending on the number of years you want to use, depending on the number that you want to use as far as your interest costs and so on are concerned, you are talking $100 million to $200 million a year for that kind of a situation.

Additionally, you have got about a 10-percent reduced capacity that you have to make up. We have to make it up with oil-fired capacity in New York State. We don't have any other capacity to make it up with because our coal plants are base loaded. So we have that replacement cost. We have estimated that around $60 million a year.

Additionally, maintenance operation costs on those scrubbers were estimated for an additional $60 million a year.

Second, in New York State, we burned about 62 million barrels of oil a year, at least in 1980, we did.

Most of that or about half of that oil is very low sulfur oil, on the order of three-tenths percent sulfur oil. The remainder of it is in the higher sulfur oil capacity or approximately 30 million barrels a year. The differentiation between high- and low-sulfur oil will vary between the geographical locations. The differential is greater in the New York metropolitan area than it is, say, in the Great Lakes. So between $5 and $8 a barrel differential, which gets you another $200 million to $400 million a year in excess costs. But the biggest impact in New York is the loss of the savings that we are counting on with the conversion of 3,700 megawatts of present low-sulfur oil-fired capacity to coal.

It is estimated over a 15-year period and these numbers and projections are in that colored booklet I have passed out here as to our future plans—it is projected that we are going to be able to save the consumers, this is a direct passthrough on fuel costs, $15 billion over the 15-year period.

If you want to simplistically say a billion a year, you can say that, I think. Most of the savings will accrue later in the 15-year period, but that is the magnitude of the savings through coal conversions.

Mr. MOORE. Does that include scrubbing?

Mr. ANDERSON. No. That does not. That is predicated on a no-scrubbing situation.

We have taken a look at a lot of our plants as to what would happen if we had to go to scrubbers. In most cases, you will find that the cost of scrubbers wash the savings that could be accrued from coal conversions. Therefore, there is no economic incentive. Therefore, you have lost savings that you would have. It is that simple. So I guess the bottom line, when you add up all of those numbers, you are looking at something on the order of about $1.5 billion per year as the cost of 1706 to New York.

Mr. MOORE. Thank you.

Out of curiosity, how are you going to convert those boilers?

Mr. ANDERSON. Using low-sulfur coal.

Mr. Moore. So you will meet the present new source performance standard when you convert them?

Mr. Anderson. That is up for question.

Mr. Jewett. No. It won't be subject.

Mr. Anderson. They are old units. They are not made to modification. These units all burned coal back in the sixties.

Mr. Freeman. They are coal capable.

Mr. Moore. That doesn't exempt them from the law.

Mr. Freeman. If you are coal capable and you are ordered to convert or elect to convert under the latest amendment to the fuel use side, you are exempted from new source performance standards.

Mr. Moore. We are getting into a somewhat different field and that is the meaning of the most recent amendments to the Fuel Use Act, but it is your belief that you would qualify under those limits for th exemption.

Mr. Freeman. He has orders that are out. As those amendments pass, you can shortcircuit at least under some lawyers' views the older provisions by filing the notice of election.

Mr. Moore. It is interesting that that construction of the language was denied at the time we considered it in the reconciliation.

Mr. Freeman. I think it was sponsored by one of the distinguished senior members of this committee.

Mr. Moore. I would like to recapitulate. It seems to me that what each of you has said this morning is that if S. 1706 or something like it were to become law that you would comply in the three cases out of four, basically, three plants out of four, you would fundamentally comply by scrubbing as opposed to fuel switching.

Let's go down the line to make sure that is clearly what Mr. Dowd said.

Is that basically what you said, Mr. Goodman?

Mr. Goodman. I think what I said was there is going to be some option between the two and I gave you the costs for both extremes and our general view would be somewhere in between.

Mr. Moore. Mr. Ali?

Mr. Ali. I indicated that at the peaking stations we will be using low-sulfur coal.

Mr. Moore. But peaking, I would assume, would be a relatively small portion of your generating capacity, your baseload capacity you would go to scrubbing?

Mr. Ali. That is correct?

Mr. Moore. Mr. Pennington?

Mr. Pennington. I am here. Same answer.

Mr. Moore. Mr. McKnight?

Mr. McKnight. Indianapolis Power & Light would backfit 895 megawatts with FGD and burn low-sulfur coal and 758 megawatts.

Mr. Moore. About 50/50.

Mr. Runyon?

Mr. Runyon. I think that question was a little bit difficult to answer because of the allocation of the emission reductions as looking at the Mitchell bill is yet to be finalized.

Certainly, the most cost-effective means is utilizing low-sulfur coal, if that is possible to do within the constraints of the Mitchell bill.

As we interpreted the Mitchell bill, that is us interpreting it. We looked at 70 percent or above reduction. That is what drew us to an all scrubber picture. But if the allocations of those emission reductions in Ohio was such that we could comply with low-sulfur coal, we would certainly take that option.

Mr. **Moore**. Which do you think you would do?

I understood you to say just a minute ago that you would scrub.

Mr. **Runyon**. Yes, as we interpret it.

Mr. **Moore**. Mr. Smith?

Mr. **Smith**. I think if you recall, my sulfur scrubber analyses were done on older data. I think in reality if we did a detailed study, it would probably throw us to all Western coal, assuming that the boilders at the Sauet plant which are cyclone fired units can accommodate with slight tapping, in other words, on that Western coal.

So I think we would be 100 percent low-sulfur coal.

Mr. **Moore**. Just out of curiosity, do you operate in central Missouri?

Mr. **Smith**. We do, but we don't burn any Missouri coal.

Mr. **Moore**. Mr. Kaslow?

Mr. **Kaslow**. On our oil units in New England we would fuel switch, go to lower sulfur oil and we would abort some coal conversions rather than put in scrubbers, because they are physically impossible.

Mr. **Moore**. You seem to be in a unique position among all of these utilities.

Mr. **Kaslow**. We are because we are basically an oil burning area rather than coal burning area.

Mr. **Moore**. Mr. Dowd is gone, but I understood him to say that they would scrub virtually 100 percent.

Mr. **Freeman**. That is right. Except in a few places where they had physical constraints.

Mr. **Moore**. Mr. Anderson?

Mr. **Anderson**. Two things. Fuel switch at our oil-burning stations that are using high-sulfur oil now and the coal-fired stations we had to assume scrubbing because who can forecast the price with the rush that is going to go on if this kind of legislation goes though on Eastern low-sulfur coal, who knows what the price would be? You do have an idea what the price of scrubbers are.

Mr. **Moore**. For the record would you provide a list of the 15 plants which you presently plan to convert, what their present emission rates will be, what the present emission rates are, what the emission rates will be after you convert assuming you get your fuel use order and how many tons per year of sulfur that will amount to? I presume there will be some increase going from oil fired to coal fired.

Mr. **Anderson**. Yes. There will be.

Ms. **Pfifferling**. It is not 15 plants?

Mr. **Anderson**. Fifteen units. There is quite a bit of information in that booklet handed you.

Mr. **Moore**. Then the other thing is, we will make sure that each of you has a copy of the agenda. Do they have copies of the agenda now?

Mr. Freeman. I think everybody had it except Mr. Dowd who got in late this morning.

Mr. Moore. If you would please respond to the questions.

Mr. Freeman. And Mr. Anderson, but I will see that he gets one.

Mr. Moore. Respond to the questions which were on the agenda, including the question about assumptions and methodology and if you would also please provide the information which in various ways has been requested several times this morning on individual plants, what would happen to that plant, capacities, age, anticipated retirement, reserves, present reserves, and so on. If it is helpful we can reduce all of that request to a writing and convey to you. Would that be better?

Mr. Freeman. I think it would be. When you have a transcript available, I think we can get the letter out to everybody.

Mr. Moore. I will defer to other folks who may or may not have questions at this point. Sueanne Pfifferling?

Ms. Pfifferling. I have one question of Mr. Runyon. When the first Mansfield plant came on line, what was the impact on rates in that plant?

Mr. Runyon. That plant is part of our total system. Our system is about 5,800 megawatts. That plant is about 2,380 megawatts. When it came on line, the generation cost was all completely compiled into the total system cost. So right offhand, I cannot give you that number. But it would be hidden. I can say this. That the Bruce Mansfield cost as a result of the scrubber operating maintenance costs right now is running about 50 percent of the total operating and maintenance costs of the plant. That is excluding fuel.

Ms. Pfifferling. Would there have been a chance that that plant could have increased the average residential customer's electric bill by 40 percent, that single plant?

Mr. Runyon. Not in the total system of 5,800 megawatts.

Ms. Pfifferling. The reason I ask this is because the total capital costs that you talk about for the plant, including the scrubber, but the total capital cost, seem to be about the same as the total capital cost that you talk about retrofitting scrubbers in the rest of the system, about $1½ billion. I just wondered what the effect of $1.5 billion capital expenditure that you did have in your system, how that affected residential rates.

Mr. Runyon. Let me make one other clarification here. The Mansfield plant is a unit owned by four other utilities, a percentage.

Ms. Pfifferling. So you only had a percent of that?

Mr. Runyon. Yes. We all had a percentage of it. That is correct. So I could give you exact figures on the impact, but that kind of changes that somewhat. That accounts for the difference.

Mr. McKnight. You are looking too at a piece of generating equipment that will make more kilowatt-hours and which you can then sell. When you put in a scrubber for a billion dollars or whatever that makes no more kilowatt-hours that you can sell, that burden is not spread over any more customers or any more generation.

Please understand. There is a substantial difference.

Ms. Pfifferling. Supply new customers.

Mr. **McKnight**. Yes. He either sold the power to some other utility or had more customers, maybe was buying power that he quit buying.

Mr. **Runyon**. I think the $1.3 billion was a total plant cost versus the $1.3 billion which was structly for pollution scrubber-type equipment.

Mr. **Moore**. The scrubber or all pollution control equipment?

Mr. **Runyon**. Basically scrubbers on the existing plants, while the $1.3 billion in the Bruce Mansfield plant was the total cost of the plant; $400 million was the cost of the scrubbers on the plant.

Mr. **Frankel**. A question for the gentleman from the Southern Co. You mentioned that your estimates for going one route were $850 million, about the same going the other route. Would the optimum mix have been lower than that, or would they fall pretty similar or is there a stackup of some high, some low, some getting much higher per unit?

Mr. **Goodman**. You asked me per unit? I didn't understand.

Mr. **Frankel**. In a lot of these studies one finds that any particular technique depending on particular things about a particular facility, scrubbers can range from 150, maybe if you are lucky, maybe 158 kilowatts, if it was muderously constrained, it might be multiple hundred per kilowatt. Do you have a similar situation so if you made up your optimum package, instead of being one-half of $800 million, you may come in for $500 or $600 million for the optimum accommodation?

Mr. **Goodman**. I think my general view is the way we did both studies and the way you handle the money, the analysis for what an annual number would be that the order of magnitude of the right range is the $800 million range either way. If you get down to the scrubber question raised earlier, one of the things that makes the scrubber cost in dollar per kilowatt different from unit to unit, is some of those units are small. You have economics of scale. That is the reason we use those rating schedules. Some of those units were $125 a kilowatt retrofit, some were $400 million. It was a function of being on the side of the river, 100-megawatt unit versus an 800-megawatt unit, all of those variables are handled in there.

We can try to show you that in the response we give you. How they vary based on unit size and difficulty of putting them in at a given site.

Mr. **Smith**. I can build you a scrubber for $65 a kilowatt but it isn't going to work. If you make my coal costs in Illinois cost $45 a ton, then it won't cost anything, because Western coal will be cheaper. It is just a pushing of numbers around. You have to look hard.

Mr. **Moore**. That is why we wanted you people here today.

Mr. **Frankel**. The thing we hope to learn from the system studies would be the fine studies of the particulars of the system as opposed to the macrogeneration we heard yesterday. One of the things is the costs are different from unit to unit depending on conditions on site. I was wondering if in actually responding to the Mitchell bill or to whatever kind of reduction that might come through if something like this were passed, you would optimize over the system, pick the least cost units to do each thing on, whether you would come in at significantly less than the $800 million total bill for this amount of reduction.

Mr. GOODMAN. Obviously we would try to do that if we had a mandate to do it. There are several interesting questions brought up. It has been assumed that the scrubber would have the same removal efficiency and reporting requirements of 30-day rolling average compliance, that is required under the new source performance standards. If you back off and said you are going to make them do this on an annual basis, give me a lot of slack in the middle where I don't have near as demanding requirements on the equipment, as Jerry pointed out, there are all sorts of levels equipment. We have made the analysis that you are going to have redundancy on the equipment and meet a 30-day rolling average high availability requirement.

Those things can impact your decisions on how you are going to optimize the requirements on this regulation. As was said by some others until you really see more definition of what you might have to do, it is awfully hard to get that specific.

Mr. SMITH. On the availability, I don't think realistically, when you put on an extra module for example, you have redundancy, you cannot get 100-percent availability on the scrubber. Regardless of how many modules you throw out there, I don't think you will get the 100 percent. You are going to affect the capacity some. You have got to pay the capacity charge somewhere. You have to build additional capacity.

Mr. GOODMAN. We didn't make an estimate on the additional capacity. It was just uncertain. The question earlier, low-sulfur coal, if it was there for the price we are currently buying, at least it keeps us out of that big blip of high capital requirements for a period of 3 or 4 years of construction. That is going to drive an awful lot of people if they can avoid that, although $850 million increase in the fuel bill is going to be held in abeyance for the Public Service Commission, how you are going to get that rate is not trivial either.

There is a big driving force if you can do it that way and still meet all of these requirements. When we talk about growth, my statement was the 0.2 million, then when I started talking about growth, I have used that all up. I have got to put some scrubbers in if I am going to offset future growth in NSO_x and SO_x. That comes from existing plants. It is not new ones coming on for us. It is greater capacity on existing units. 1980 was a poor economic year for us. We weren't using them to the level that they were designed to be used.

Mr. MOORE. Is that true of everybody here?

Mr. FREEMAN. I think that is true if we go to the macromodels. Remember yesterday, everybody sort of agreed that the two most important factors from a cost point of view were first that the total tonnage actually required of the utility industry and the second more important part of that problem was the point we have just been talking about.

Mr. SMITH. Ratemaking is a tough business these days.

Mr. MOORE. What would be the effect of permitting construction work in progress for pollution control equipment to be included in your current rate base?

Mr. **Birk**. Currently, Missouri has an expressed statutory provision that restricts any construction utility progress in the rate base. As a matter of fact, it was initiated through the initiative petition processes and antinuclear proposition that remains on the books since 1976. So I would suspect there would be quite an uproar over any attempt to dislodge it from the present status.

Mr. **Moore**. I am not talking about nuclear construction work in progress. I am talking about scrubbers.

Mr. **Birk**. I am just giving you the progress. Any effort to unloosen it would meet with stiff opposition. But it ought to be done.

Mr. **Freeman**. I think everyone here would agree that it is far easier to raise money if you have real earnings instead of paper earnings and the whole, with many of these systems here, where they are denied construction work in progress, if you look at their earnings which are half of the real earnings and the other half are paper earnings and the financial community discounts those paper earnings and what limited capital there is available in the utility industry ususally goes to the system with the higher actual earnings. So people who are under substantial capital projects have the hardest time in today's money markets raising the capital.

Ironically the people who have the least difficulty with raising it are the people who don't need it very much.

Mr. **Thomasiam**. I would like to ask a general question. How many utilities here are not not allowed to put pollution control equipment in the rate base?

Mr. **Freeman**. In the rate base at all or construction work in progress?

Mr. **Thomasiam**. Construction work in progress in the rate base.

Mr. **Goodman**. It depends on the study.

Mr. **Thomasiam**. You are saying your State does it?

Mr. **Freeman**. So we have it on the record, we had a response from Union Electric and from the Indiana companies that they cannot do that, Southern Co. says its experience varies in the four different States that it operates in.

Mr. **Runyon**. We have construction work in progress.

Mr. **Freeman**. Environmental stuff? Jack?

Mr. **Kaslow**. FERC regulation allows it for construction work in progress, so any utility in FERC jurisdiction is allowed to do that.

Mr. **Freeman**. You are the only system in the country that is really predominantly under FERC rather than State.

Mr. **Thomasiam**. Another question on that same topic. How many here are allowed automatic fuel adjustment?

Mr. **Freeman**. How many people have automatic fuel adjustments in rates in States in which they operate?

Mr. **Kaslow**. Yes; with a caveat.

Mr. **Goodman**. Define "automatic."

Mr. **Thomasiam**. You get a fuel adjustment without a hearing although later you do have to go through it.

Mr. **Goodman**. No. You have to have a hearing.

Mr. **Kaslow**. Same here.

Mr. **Runyon**. Hearing.

Mr. **Thomasiam**. What is the timelag between your request for a hearing and a hearing and then putting in a fuel adjustment base?

Mr. **Runyon**. In our case we have fuel adjustment hearings every 6 months.

Mr. **Thomasiam**. Another general observation. You can comment on this. It appears that all the costs that you presented today, each of the systems have been first year annualized costs and they are not real levelized costs over the life of the plant.

Mr. **Goodman**. Our are levelized.

Mr. **Thomasiam**. You use a nominal capital charge of 20, 22 percent?

Mr. **Goodman**. I told you what would be the increased fuel. The fuel I gave you was an increased fuel price. That increase as it goes forward will stay the same. It is an adjustment to current fuel.

Mr. **Thomasiam**. I would venture anyone using 20 percent fixed capital costs are not presenting levelized costs.

Mr. **Pennington**. On what basis?

Mr. **Thomasiam**. You have got to understand that a lot of these macrostudies are presenting levelized annual costs. That is why your dollars are much higher because they are going to go down over the life of the bill or the regulation.

Mr. **Pennington**. I submit that a levelized fixed charge rate of 20 percent for 30-year life investment is probably bottom dollar today. Anything shorter lived will be much higher than that.

Mr. **Thomasiam**. Can you document that?

Mr. **Pennington**. Surely.

Mr. **More**. Would you?

Mr. **Pennington**. Yes.

Mr. **Smith**. I would only comment that my statement of cost would more than offset any levelized cost.

Mr. **Freeman**. Charles Goodman has to go to catch a plane or else he has to stand around to see if he can get on standby, if there are any further questions that you have of him about the Southern Co. that you would like to ask him, if you could do that, and get him out of here.

Mr. **Parker**. You mentioned earlier some work you had done with EPA on low NO_x burners. If you could provide us with any documentation on their reliability of workings, it would be useful for us to try to decide whether or not the NO_x for SO_x trade is a feasible alternative here. That would be open to all of the rest of the companies, if you have got any NO_x work, it would be useful for us to know if you have any pilot plants or anything.

Mr. **Friedman**. How do your own experiences with the experimental scrubbers that you said your company operates, how do they compare with the TVA costs? I notice you opted for using the radian numbers.

Mr. **Goodman**. Remember that our studies have been on 20-megawatt pilot plants. But our view is we use the TVA data. It comes out very similar at least as represented by the radian, within 10 or 20 percent. You have all of those uncertainties on the retrofit. When you have those sitting there, the radian study, the TVA is all you have got. We use it publicly instead of getting into shouting matches.

Mr. **Freeman**. I would also say that back when we had our revised resource performance standard rulemaking, the entire utility industry used the TVA data for the cost on new plant. I think again I emphasize the fact that I do think you have to, that the cost of new plants are not representative and I ask if anybody here on the panel would just comment on that.

Mr. **Smith**. What is the question?

Mr. **Freeman**. The costs whether available from the industry or TVA or other sources, costs of scrubbers for new plants are not really directly representative of the cost of retrofit and they would be substantially higher.

Mr. **Friedman**. That 20 percent, 30 percent, 100 percent?

Mr. **Goodman** You remember the radian study, the latest version had what they called a retrofit factor that implied the complexity. For us that ranged multiplying your dollar per kilowatt, that varied from unit size and other variables by anything from 1.1 to 1.4. It has that kind of multiplier.

Mr. **Moore**. I want to pass around this list and if you would write down your address and telephone number so that we can mail you these followup questions.

Mr. **Smith**. I think it is important to look at an existing system and built anew, and that being the Mansfield system and adjust those costs, that something no one can dispute. Those are dollars out there. We can guess at future costs on the lot. But if you have something as a scale there, the bucks have been paid.

Mr. **Freeman**. It also is probably the biggest unit that has been operating using what percent coal?

Mr. **Runyon**. It was designed for 4.3-percent coal. We have actually been burning in the area of 3 to 3½ percent. It depends on the particular coal supply that we are using. But we can go up to as high as 4.3 and still meet——

Mr. **Freeman**. A lot of the coal we are talking about, people like AEP, are substantially above that sulfur content.

Mr. **Runyon**. It is very important when you talk about scrubbing, throw all the different scrubbers into some kind of a computer system and you punch a button that says, this is what they cost per kilowatt hour is you almost have to go back and look at them individually and say, here is a scrubber on a certain sized unit burning high sulfur coal with no basis, with a certain type of material. This is what we are looking at. That is the kind of data you have to compare.

I think the Bruce Mansfield probably offers that example of what I am talking about, a closed system, complete scrubbing, no bypass, high sulfur coal, sludge disposal and the whole works.

Mr. **Friedman**. You mentioned something, I think was rather significant. You said the $2.5 billion of capital as compared to the capital that you already own was a very large percentage and that your financial people were very worried.

Can you give me a number that if you were to talk into your financial group they would say we wouldn't be in trouble with it?

Mr. **Freeman**. We might ask them to send that data to some of the key investment banking firms in New York.

Mr. **Goodman**. Let me respond to the question.

If we got this thing that is currently the order of $1.25 billion a year construction budget, you are currently living with and causes great consternation, do we cancel, get out, the internal discussion with them is, we have pushed it to the limit and we say we are going to finish this construction.

That is what all of them sit around and talk about. I walk in with something like $2.5 billion in a 3-year period needed, current dollars in the late 1980's, they are going to ask me where it rolls back to. But I am really banking my factor of two on their current, what they feel is the limits to themselves on raising capital.

I have gone in and told them it is a number about double that. I might go in and say 10 percent on the current construction budget or something and they might say, well, we are in trouble already. My God, man, we have doubled and tripled it when I talk to them about $2.5 billion.

Mr. **Friedman**. If that were a 5-year period, then you are saying on the order of, 25, 40 percent?

Mr. **Goodman**. That period has pushed them to the wall, to get any more money out of them for anything, internally for us to do internal projects of any kind, you can't get money for it, even if they are big return benefit ones. We are close to that point right now.

Mr. **Moore**. Let me ask a question which is very general in nature and, perhaps, inappropriate. Nonetheless, I will put it to you.

Let's assume that good public policy demands that we achieve an emissions reduction of sulfur of 50 percent and further assume that good public policy demands that the achievement of that reduction not be delayed until 2010 or 2020, when much of the equipment now on line will wear out and be replaced.

Do you have a feeling on what the most efficient way to achieve that reduction would be for purposes of your utilities?

You are nodding your head vigorously.

Mr. **Birk**. I am not sure it would be the most efficient way under current conditions but nuclear power comes to mind, for example.

Mr. **Moore**. Anybody else?

Mr. **Runyon**. We are looking right now at some of the 10, 20, 30, 50, 70 percent options. We find that certainly you get below 70, that the low-sulfur coal combination scrubber would be considered. They would vary as your percentage—for example, 50-percent reduction would be a combination of low-sulfur coal switching to low-sulfur coal and maybe installing scrubbers on certain plants where their sites are such that you can do it in a less costly manner, that type of combination that you would look at specifically as you would know the percentage reduction required.

Mr. **Goodman**. I think when we tried to do that at home there is a fear that we get in the middle of it. Obviously we roll back far enough when we are currently under a 3-pound per million Btu limit, you get into options where a little bit of blending and low-sulfur coal and those kinds of things, even some of this emission dispatch-type of discussion, you may pick it up. But our problem is, there is a point in there. This intermediate step has got to be tied to some benefit out here that you are going to see a late CWIP being solified or some environmental factor.

Our view is there is going to be a short fuse on what people will tolerate until they see that improvement. That means we are looking at options; that is, we would be committed to link our current coal contract policies to comply with SIP's that will cause a hell of a lot of dollars to be paid.

Once we have committed that way, then find out we have to go further, do something much more severe because your tradeoffs specifically between scrubbers and long-term low-sulfur coal contracts are not minor.

Getting out of one of those coal contracts, after tying yours up with long-term low-sulfur coal contracts to blend and do other things that way which are more appropriate for some of these intermediate steps versus going ahead and putting the mostly efficient removal equipment scrubbers I can find on some big units, you don't want to get caught in the middle of those two. That is just the bottom line. We get caught with this no-growth scenario, the low-sulfur fuel will not be adequate because we have to cope with growth.

You have to go back to what we are trying to answer. There is some great environmental problem out there driving this, yet that problem does not have a good measure like the traditional ambient air quality SO_2 whereby reduced emissions in the air, if that number went down. So, I think we do those studies but it is that fear that makes it a real economic risk to us.

Mr. McKnight. I think Dr. Goodman's point goes to show you why trading of any excess reduction given that any of us could possibly afford to get an excess of reduction, anybody that would overshoot on their reduction would be foolish to go out and barter this to somebody else, when, one, he may need it for this future growth or somebody may come back next month and say we want another 10 percent out of you and if you already traded off your excess emission, you have to go do it again.

Mr. Freeman. Let me say one thing that was brought out by the witnesses yesterday, not only ICF in terms of summarizing what they have done for us, EPA and National Wildlife, but I think also by the EPA and DOE people as well and perhaps by the OTA people; that is, that if you had to make whatever mandated reductions you would have to make, you were given 1995 rather than 1900, you would have a lot more options to have available to you and you might be able to substantially reduce your aggregate costs because to the extent that you actually wanted to go out and build a new plant, if we said go build a new plant, get licensing and build it, there is no way to bring any of those plants in before 10 years; also the technology would probably have substantially improved.

We would have a lot more experience at least as far as scrubbers are concerned.

Mr. Smith. It is difficult for me to believe we will have a whole lot better than 90-percent reduction. We may get somewhere——

Mr. Freeman. But the costs might go down.

Mr. Smith. I don't believe that, frankly. I have not seen that happen since I entered my experience in dealing with scrubbers and I have followed that with more than casual interest.

I don't see it happening. I don't think the availability is there today that we really ought to have to do what the law seems to demand you do.

I simply believe you are going to have to put more bucks in it to do that. If you wait long enough, obviously, acid rain control will cost nothing because we will have driven the prices and all other things.

I should also point out in my analysis that it would appear that at my older plant, the cost of low-sulfur coal differential is much less than other plants but it is because the cost of that coal presently is high.

It is not that the rate is getting any bargain. As those two costs come together, then there is no differential.

Mr. **Moore**. I don't want to cause you to miss your plane. I want to ask you one further question:

If it will cause you to miss your plane, don't answer it; that is, the question of whether the imposition of an intermediate emissions reduction goal would cause the utility to opt for a strategy which make a larger longer term emissions goal either unachievable or much more costly.

Mr. **Goodman**. I think it could make it much more costly. I will use that example. The intermediate which says you will blend more low-sulfur coal.

Our view is any coal contractor we talk to right now, there is going to be a premium on that. The coal suppliers have the same problems we do, where do we get the capital to open the mine?

They are going to get if from us. You are going to have to advance them so many hundred million dollars to help them get in to the business. They are going to get into that business. They want you to be around for 30 years. So you make all that commitment and then something happens down there that says you got to do so much better in the low-sulfur coal to really help. So you should have gone the scrbber route instead.

So now you are going to scrub that highly expensive low-sulfur coal to do it, when your previous alternative would have been to keep your current coal and scrub from the start and have that extra reserve or shoot at another target.

Those are very real. We have coal contracts that we buy the mine for the life of it, if we get out of it. There is no miner charge to get out of some of those agreements because we wanted them in. We wanted to lock them up. They have locked us up too. I think that is an example of where you could get yourselves in a box.

Mr. **Freeman**. You would certainly be better off in knowing whether you needed to take a second step or not. It would certaionly remove any—I mean, once you buy the scrubber you are not going to not operate the plant without the scrubber.

Mr. **Goodman**. That is true. Once you have got the scrubber, I agree. Maybe I am not understanding the question you are asking.

Mr. **Moore**. What I am basically saying is, take two options. I give you option A, I say that by *x* number of years in the future you have got to achieve a 50-percent reduction in emissions and option B is that I say to you that by a date which is, say, half of that, first date, you have got to achieve 25 percent and then you have got to achieve ultimately 50 percent.

What is the effect of interposing that intermediate step of 25 percent?

Mr. **Goodman**. That may be different. I would have to think about that. I was answering more the question of you shoot at some intermediate compromise target, then it gets ratcheted down on you again.

What you are saying is a different element. Obviously, you would like to put off those expenses as long as you could. The only negative would be you would have to spend money sooner than you might otherwise have to spend it.

Mr. **Moore**. Instead of achieving a 25-percent reduction on the earlier date, you might go ahead and hit the 50 percent, if you could.

Mr. **Goodman**. At the later date, which would save me having to spend all of that money in the interim.

Mr. **Freeman**. That presupposes. The real problem there is, I think the answer comes out one way. If you know that it is in the public interest to take the second step, or whether that is open for reevaluation in light of the studies that are now going on. That goes back to the testimony you heard last week where some of the people said they didn't think you would get any benefits at all or none would be protectable. Then we had some witnesses say you may make the thing worse instead of better because it is the short-range transport theory which is the principal cause and that would tie in the Hubbard-Brook data.

The DOE study that I mentioned yesterday which I brought copies of to give people here, if you commit us to a certain course of action that results in increased oil emission and as part of the scenario, in obtaining these reductions, that is clearly what we hear from New England and from New York, then we may make things actually worse in those States, in those States that have the principal, like acidification problems.

Mr. **Moore**. You and I must have heard different witnesses last week because that is not what I heard the witnesses say.

Mr. **Freedman**. Dr. Mohnen said you may make things worse.

Mr. **Moore**. Dr. Mohnen suggested that what we ought to be seeking is a 75-percent reduction. I don't want that. That is not part of today's discussion. Today's discussion is if the members of this committee and if the Members of this Congress decide that a 50- or 75-percent reduction is desirable social policy for this country, a desirable national goal, I understand that some of the people here might disagree with that judgment, the question is, what is the most efficient way to achieve that reduction? That is what I was trying to get at, and trying to determine whether interposing an intermediate goal would make the achievement of the ultimate goal more expensive or less expensive, easier or harder or specifically whether an intermediate goal would cause you to say buy low sulfur coal but that option would be inconsistent with the long-range goal which might require scrubbing.

Mr. **Goodman**. My view is you wouldn't make that bad intermediate step. My response was more related to that previous thing, that I am not sure how anyone is going to measure benefit, so we go out, do all of these things, then whatever somebody was trying to measure didn't improve, then we go another step.

Mr. **McKnight**. You opt against a person that is making a larger capital investment in a scrubber if you impose intermediate goals, because if we started today to design we would be very fortunate to be able to build those things by 1990.

Mr. **Moore**. thank you, very much.

Any more questions or should we go to lunch?

Mr. **Smith**. I would like to thank you.

Mr. **Freeman**. Thank you on behalf of us for having us here. I do think that we should mention, there is one thing that came up indirectly today where we think we have all got to give further thought to; that is, today we have heard about direct costs from actual systems, estimates while I think largely build in the answer to the question I think that John Jewett asked about the model, whether their models take friction costs into account.

I think their answer was they clearly don't. Today I think most of us would agree that in the estimate they do take friction costs into account. That accounts, plus the specifics and the facts for the apparent difference in the macromodel studies and individual system studies.

We also heard yesterday about secondary costs in terms of unemployment effects in the mine industry and dislocation of the coal markets.

The one thing we don't have any information on and that is if we are talking about substantial rate increases in these systems, there are other secondary effects that are caused largely through the rate impact on energy intensive industries where these rates will be passed up to and what will be the impact on those industries in terms of their ability to pass those costs on or not pass them on and what the unemployment effects might be.

Mr. **Moore**. George, you are always the consumer advocate and that was an excellent closing statement. I won't say whether it was for the defense or not. I won't talk about the death of lakes and streams and what that means to other regions.

Thank you folks, very much.

[Whereupon, at 1:15 p.m., the hearing in the above-entitled matter was recessed.]

[Responses to written questions follow:]

[The following are the questions submitted to the various utility companies to be answered for the record]

NOTE: IN RESPONDING TO QUESTIONS, PLEASE EXPRESS ALL COSTS IN CONSTANT, DOLLARS (1980). ALSO, PLEASE BE SPECIFIC ABOUT YOUR COSTS OF POLLUTION CONTROL ALTERNATIVES AS POSSIBLE.

1. (a) If your estimate of scrubber costs varied by more than 50 percent from the estimates in the CBO appendix, please explain why. If your estimated costs for cleaner fuels vary by more than 30 percent, again explain. Also, please provide historical fuel prices (by SO_2 emission rate) paid by your utility.

   (b) Regarding scrubber capital costs, please provide estimates of dollars-per-kilowatt for each unit to be retrofitted.

2. When calculating percentage increases in electricity rates due to an acid rain control program, do these percentages remain constant past 1990 (e.g., 2000, 2010)?

3. If no additional regulations are imposed will your utility be reducing emissions from current actual levels anyway (e.g., to meet SIP compliance, retirement, etc.)? Were the costs of these reductions included in your cost estimates?

4. (a) If the emission reductions required by an acid rain control program were 80 percent of the tonnage assumed in your calculations, by how much would your costs be reduced (provide your best estimate, e.g., 10 percent, 25 percent, 50 percent reduction in cost)?

   (b) If the emission reductions were 60 percent of the tonnage assumed?

   (c) All other things being equal, if S. 1706 as now drafted required a 5 million ton SO_2 reduction from current levels rather than 10 million tons, how would it affect key factors such as:

   --total capital costs
   --$/ton removed
   --electricity rates
   --annual costs.

5. If you were required to reduce emissions under S. 1706, in what three ways (in order of priority) might utility costs of the control program be reduced (e.g., automatic fuel price adjustment clauses) and in what three ways might consumer costs be reduced.

6. Please explain your choice of the components of carrying charges on capital investment. What do you assume as to the availability of pollution control bonds?

7. What is the weighted cost of capital used in your assumptions? Is that the same rate allowed by your public utility commission in rate-setting?

8. (a) What portion of CWIP, if any, are you allowed to place in your rate base? What portion of current assets are AFDUC? What is your present bond-rating?

   (b) What would be the impact on projected reduction costs of allowing CWIP for pollution control equipment into your current rate base?

9. Where do you purchase your coal and what is its delivered price? What is the method and cost of transportation, in distance hauled?

10. What percentage of pollution control equipment have you financed with municipal bonds (pollution revenue bonds)?

11. About how many points below the market is the interest charge on this form of financing? Do you intend to finance future pollution control investments in the same manner?

12. If the 1971 NSPS replaced the current standards for new power plants, what type of control method would you use and where would you buy your coal? Why?

13. What are the projected revenue requirements of your system for each year with S. 1706, versus revenue requirements for the same years without S. 1706?

14. Please provide growth rate assumptions to years 1990 and 2000 and your current and projected reserve margins.

15. How much and from what markets do you intend to purchase coal under a reduction program similar to S. 1706?

16. Provide information on the age, capacity, sulphur and NO_x emission rates, and expected retirement dates for each plant in your system with and without a reduction program similar to S. 1706. Given current replacement costs please explain any differences between the two dates as fully as possible.

17. (a) Please provide a detailed breakdown of scrubber costs, including whether your estimates include scrubber spares.

    (b) Provide information on the reduction percentage, age and reduction in operating efficiencies from currently-operating scrubbers in your system.

18. Please indicate what percentage of the coal burned by your system is washed and why it is washed (environment, corrosion prevention, etc.). What percentage of sulfur is removed?

19. How much of your coal comes from mines outside the S. 1706 arms region?

20. Provide your analysis of the use of NO_x controls as a partial or complete alternative reduction strategy.

21. What would be the impact, on projected reduction costs, of allowing CWIP for pollution control equipment into your current rate base?

22. Provide any documentation on reliability, or effectiveness and cost of NO_x control devices.

23. Would the imposition of mid-term emissions (e.g., 5 million tons at 5 years if the total goal is 10 million tons in 10 years) reductions increase or decrease long-term reduction costs? Would it alter your choice of reduction methods?

24. If the Congress decides that a 50 or 75 percent reduction in SO_2/NO_x emissions is a necessary goal for this country, what is your view of the most efficient means of achieving it?

25. Please state what percentage of your electricity is either received from or shipped to other utilities. Please also state what percentage of your power is generated at facilities which are owned or operated with other utilities.

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June 16, 1982

Mr. Curtis Moore
Senate Committee on the
Environment and Public
Works
Room 4202
Dirksen Senate Office Building
Washington, D.C. 20510

Re: Acid Rain Control Costs - Errata in
June 10, 1982 Letter

Dear Mr. Moore:

AEP responded to the Senate Environment Committee Staff's request for information on acid rain control costs in my June 10 letter. (I hope that you received the letter during the afternoon of June 11.) Because the June 10 letter was prepared at break-neck speed, several errors became apparent upon our review. Please make note of the following:

(a) The first sentence in the answer to Question #9 on Page 9 should read--"In 1980, AEP System coal was purchased from 198 mines operated by 86 suppliers . . . ."

(b) The next-to-last sentence in the answer to Question #17 on Page 14 should read--"This equates to a heat rate penalty of .202 mils/KWHR."

Sincerely,

A. Joseph Dowd

A. Joseph Dowd

AJD/jpw

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June 10, 1982

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Re: Acid Rain Control Costs

Dear Mr. Moore:

This letter responds on behalf of American Electric Power (AEP) to the Senate Environment Committee Staff's inquiry concerning the cost impact of S. 1706 (and other acid rain control bills.) As a preliminary matter, AEP stresses that the deadline for answering the staff's questions is well nigh impossible. We received the staff's lengthy list of highly specific interrogatories by telecopy at noon on June 9 with the understanding that our answers are due no later than June 11. Taking into account time for transmittal, this allows us less than two business days for turn-around. The combination of short preparation time and detailed, company/plant-specific questions on coal supplies, projected operating practices, financial information, pollution control equipment, etc., is

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particularly distressing when we take into account the size and complexity of the AEP System. AEP has eight operating company subsidiaries located in seven states. The operating company subsidiaries own and operate no fewer than 17 coal-fired plants comprised of 47 generating units. In 1981, the AEP plants consumed more than 42,700,000 tons of coal, which came from a multiplicity of suppliers in addition to System-owned mines. Under these circumstances, it is truly impossible to answer all the questions in the level of detail requested. (Preparation of this response has required the efforts of a half-dozen AEP employees located in four different cities.)

We enclose three AEP documents tnat we believe will provide necessary factual background on the AEP position on the cost impact of S. 1706:

(i) "AEP Acid Rain Rebuttal Survey," undated.

(ii) "Economic Impact on the AEP System of Compliance with the Mitchell Bill," dated February 23, 1982; and

(iii) "AEP Response to Congressional Research Service Critique Entitled 'Comparison of Cost Estimate for 10 Million Ton Reduction in SO_2 Emissions.'"

While these documents obviously do not respond directly to the staff questionnaire, they do contain information that is relevant to the topic of acid rain control costs, both regarding the Mitchell Bill and other acid rain control strategies. (In particular, the "Acid Rain Rebuttal Survey" addresses the following four scenarios" (a) 4 lbs. SO_2 cap, (b) 2 lbs. SO_2 cap,

(c) 30% System-wide SO_2 emissions reduction, and (d) 10% System-wide SO_2 emissions reduction).

Response to Questionnaire

QUESTION #1

(a) AEP's estimate for installed scrubber costs ranges from $300-$470/kw (includes AFUDC) in 1981 dollars. Costs before accounting for AFUDC range from $200-$350/kw in 1981 dollars. In the DBO Appendix Table B(2), costs of both SO_2 and particulate control for high sulfur coal average approximately $230. There appears to be a substantial difference in the cost estimates.

A reasonable explanation for much of this difference can be found in the CBO Appendix itself, where it is stated on p. 83:

> "The costs presented in these tables give rough approximations of the cost-penalty involved; only a case-by-case analysis of actual fuel-switching situations could provide an accurate estimate."

AEP used the latest information available on FGD systems, based on a recent BACT analysis conducted for a planned new generating plant, and carried out an extensive site-by-site analysis for the units where retrofits were envisioned. It is believed that the cost estimates are sufficiently accurate for this type of study.

If a fully washed coal replaces a run-of-mine or partially washed coal from the same source, the fully washed coal (cleaner fuel) will not give rise to more than a 30% cost increase in terms of ¢/MMBTU. If the "cleaner fuel" represents a replacement for an existing supply source, it is probable that the cost increase will exceed 30%. Because of generally higher natural mining costs and longer transportation routes, at least on the AEP System, lower sulfur (cleaner fuel) will be significantly more expensive. Compounding this added expense will be the significantly larger demand for lower sulfur fuel which will raise prices due to mining deeper and thinner seam lower sulfur coals. In 1980, prices paid by SO_2 category were as follows:

#SO_2 Class	Tons	Price/ ¢/MMBTU Delivered
<1.2	8,355,390	175.7
1.2-1.6	10,467,995	160.7
1.6-3.0	5,914,814	161.4
3.0-6.0	3,413,026	122.7
6.0-9.0	16,743,038	135.5
>9.0	622,188	105.6
	45,516,451	150.7

(b) Attached as Figure 1 is a tabular breakdown of the range of scrubber retrofit costs that will be experienced across the AEP System if the Mitchell Bill is enacted. (This table includes pertinent examples but not all AEP units.)

FIGURE 1

SCRUBBER RETROFIT COSTS

Unit to be Retrofitted	Estimated FGD Capital Cost, $/kw (1981 dollars)
Rockport 1-2	307
Tanners Creek 4	445
Breed	473
Conesville 4	367
Gavin 1-2	307
Muskingum River 2-4	412
Amos 1-2	330
Amos 3	307
Mountaineer	307
Clinch River (1 unit)	427
Big Sandy 2	330

QUESTION #2

No, the percentage increases will probably decrease, because the bulk of compliance costs will be fixed costs. As electricity sales increase in the future, the proportional impact of these fixed costs on customer rates will likely decrease gradually. However, it should be noted that this question is highly speculative and the answer to it could be changed by unforeseen future events.

QUESTION #3

AEP is not required to reduce SO_2 emissions across the board under current SIP requirements. In the case of Columbus and Southern Ohio Electric Company's Conesville Plant, the present SIP requirements (as embodied in a proposed Delayed Compliance Order) will require some incremental expenditures to provide for coal washing. These coal washing-related costs are comparatively small when considered in connection with the much greater incremental costs of the Mitchell Bill, which would require a combination of premature unit retirement and scrubbing.

Similarly, developing SIP requirements may require incremental coal washing costs at Muskingum River Plant beyond the coal washing technology already in place. The coal washing costs are comparatively small when weighed against the costs of scrubbing at Muskingum River Plant.

In the overwhelming majority of cases over AEP's large system, current SIP requirements do not entail major SO_2 cutbacks so that the incremental costs imposed by the Mitchell Bill are truly "incremental," because they are costs that otherwise would not have to be borne by AEP and its customers.

QUESTION #4

(a)(b) Providing cost estimates for SO_2 tonnage reductions--equal to 80% and 60% of the more-than-1,350,000 tons SO_2 reduction called for under the Mitchell Bill--would require AEP to perform a detailed study for which the June 11 deadline does not allow. (AEP stresses in its Response to the CRS Critique that its Mitchell Bill cost study matches up emission reductions to the control options actually available at each plant site. To consider the 80%-of-Mitchell and 60%-of-Mitchell scenarios would require a similar site-specific study.) As pointed out above, however, AEP has considered alternative SO_2 emissions reduction strategies, which are described in the attached "Acid Rain Rebuttal Survey." Approximate capital costs of each of these scenarios are set forth below:

2 lb. SO_2 Cap -- $2.9 billion (1981 dollars)
4 lbs. SO_2 Cap -- $1.95 billion (1981 dollars)
30% SO_2 Reduction -- $1.57 billion (1981 dollars)
10% SO_2 Reduction -- $ .45 billion (1981 dollars)

(c) If the total SO_2 emission reduction requirement were reduced from 10 million tons to 5 million tons, the following changes in costs would take place:

	10-Million Ton Req't.	5-Million Ton Req't.	Percent Change
Capital Costs	$\$7.2 \times 10^9$	$\$2.5 \times 10^9$	-65%
$/Ton Removed	1460	1035	-29%
Electricity Rates	+63%	+22%	-65%
Annual Costs	2.0×10^9	0.7×10^9	-65%

QUESTION #5

Unintelligible.

QUESTION #6

The components of annual carrying charges on capital investment include the following:

(1) Return on investment (cost of capital)

(2) Provision for depreciation

(3) Federal income taxes

(4) Property taxes, administrative and general expenses

The possible availability of pollution control bonds was not specifically taken into account in the ROI component of annual carrying charges.

QUESTION #7

The weighted cost of capital assumed in the AEP System study is 14.17%. This figure is intended for use in general system studies and reflects a 25% embedded and 75% incremental weighting of capital costs. In general, it is 2-3 percentage points greater than the returns allowed by the regulatory commissions in the seven states served by the AEP System.

QUESTION #8

(a) CWIP allowance and AFUDC vary from jurisdiction to jurisdiction in the area in which AEP operates. It is therefore difficult to generalize in answer to this question. First mortgage bonds of the AEP System operating companies are generally rated Baa (Moody's) or the equivalent.

(b) Any answer to this question would be highly speculative and subject to unpredictable future developments, including investor behavior and state law changes.

QUESTION #9

In 1980, AEP System coal was purchased from 152 mines operated by 56 suppliers, located in some 9 states. Truck, rail, barge and overland conveyor modes, and combinations of those modes were utilized to deliver the 45.5 million tons. The overall transportation costs range from 1 to 141¢/MMBTU. In 1980, 10.0% was delivered by truck, 32.1% by rail, 16.8% by barge, 25.5% by conveyor, and 15.6% by combination rail/river.

QUESTION #10

Approximately 80%. (Although a high proportion of AEP's pollution control equipment has been financed by pollution control bonds in the past, in order to finance all pollution control equipment by pollution bonds, it has been and would continue to be necessary to finance all other capital expenditures with a disproportionately high amount of equity. Also, there is little reason to believe that pollution bonds would be available to finance replacement capacity made necessary by the Mitchell Bill.

QUESTION #11

At present, pollution bonds are more economical than first mortgage bonds by 250 to 500 basis points. The precise amount would be a function of the total amount of first mortgage and municipal bonds in the market at any given time, the amount of financing by an individual company at any given time and overall levels of interest rates. AEP intends to finance future pollution control investments in the most economical manner available.

QUESTION #12

This question cannot be answered in a vacuum. The answer depends on a number of site-specific factors, such as location of the plant site relative to coal supplies and transportation facilities. Given the increasingly intense scrutiny by state public service commissions on utility rates, it would be incumbent upon AEP to employ the most cost-effective control method under the specific circumstances.

QUESTION #13

A year-by-year projection of revenue requirements with and without S. 1706 has not been made. However, the AEP study indicates that annual revenue requirements would be increased by about $2 billion (in 1981 dollars) after the compliance program has been put in place.

QUESTION #14

The internal peak demand of the AEP System is currently projected to grow at an average annual rate of 3.5% to 1990 and thereafter to the year 2000 at a slightly reduced rate, i.e., about 3.3%. Generating-capacity reserve margins are currently projected at about 20% of internal peak demand for 1990. No specific reserve margins have been projected for the year 2000, but it is expected that a target reserve of about 20% of internal peak load would be appropriate for that time period.

QUESTION #15

We believe that further reductions are uneconomic and totally unwarranted. If such a program were unwisely mandated, however, current supplies, reserve areas, and transportation systems would be strained to the point of either (a) not being capable of meeting all the increased demand, (b) causing a tremendous increase in prices because of exploiting heretofore uneconomic reserves and necessitating huge capital investments at exorbitant financing costs, and (c) probable combinations of (a) and (b).

QUESTION #16

With respect to age and capacity of AEP System plants, please see the pamphlet entitled "Leadership in Electric Energy Generation." With respect to SO_2 emissions, please see Attachment 3 of the "Acid Rain Rebuttal Survey," which provides specifics regarding coal supplies at each of the AEP System coal-fired generating plants. See Figures 2 and 3 for a depiction of 1980 System-wide emissions and description of unit retirement dates

FIGURE 2

AEP Plant SO_2 - 1980 Actual Emissions

	Tons Coal (1000 Tons)	Ave. % S	Btu/Pound	Tons SO_2	#/10^6Btu	Tons NO_x
Cardinal	3,588.3	1.8	11,688	129,200	3.08	32,200
Gavin	7,809.8	2.7	9,406	421,720	5.74	70,300
Kammer	1,855.0	4.2	11,796	155,820	7.12	51,000
Mitchell	3,526.5	3.1	11,935	218,640	5.19	31,700
Muskingum	2,820.5	4.7	11,098	265,120	8.47	42,300
Amos	7,112.3	.78	12,014	110,960	1.30	64,000
Clinch River	1,594.2	.77	12,158	24,560	1.27	14,350
Glen Lyn	668.4	.88	11,813	11,760	1.49	6,010
Kanawha	1,185.9	.76	11,412	18,020	1.33	10,670
Mountaineer	917.4	.67	12,155	12,300	1.10	8,260
Sporn	2,125.9	1.01	11,587	42,520	1.74	19,100
Big Sandy	2,573.7	1.28	11,497	65,880	2.23	23,160
Breed	975.9	3.8	11,103	74,160	6.84	26,800
Tanners Creek	1,932.3	2.8	11,167.7	108,000	5.01	24,100
Conesville	3,461.4	4.6	11,053	175,000	3.53	33,400
Picway	244.7	4.1	10,983	20,060	7.47	2,200
Poston	457.1	3.7	11,396	25,400	6.49	4,100

Source - 1980 FPC-67 Reports
Filed with FERC
SO_2 determined by coal analysis
NO_x determined with EPA emission factors

FIGURE 3

AEP System
Age, Capacity, Emission Rates, and Retirement Dates
of Generating Units considered in Mitchell Bill Study

Unit	In-Service Year	Capacity (MW)	Estimated Emission Rates (1000 Tons in 1980) SO_2	NOx	Assumed Retirement Dates No Emission Reduction Program	With Emission Reduction Program
Amos 1-3	1971-73	2900	111	64	2009	No change
Big Sandy 1	1963	260	66	23	1998	No change
Big Sandy 2	1969	800			2005	No change
Breed	1960	400	74	27	1996	No change
Cardinal 1-2	1967	1200	101	32	2003	No change
Cardinal 3	1977	630	28		2013	No change
Clinch River 1-3	1958-61	720	25	14	1997	No change
Conesville 1-2	1957-59	250	56		1993-95	By 1990
Conesville 3	1962	165	34		1998	No change
Conesville 4	1973	720	70	33	2009	No change
Conesville 5-6	1976-78	750	16		2014	No change
Gavin 1-2	1974-75	2600	423	70	2011	No change
Glen Lyn 5	1944	95	4		1993	By 1990
Glen Lyn 6	1957	240	8	6	1993	No change
Kammer 1-3	1958-59	630	156	51	1995	By 1990
Kanawha River						
1-2	1953	425	18	11	1992	No change
Mitchell 1-2	1971	1460	219	32	2007	No change
Mountaineer	1980	1300	12	8	2016	No change
Muskingum River						
1-4	1953-58	840	178		1993	No change
5	1968	585	87	42	2004	No change
Picway 5	1955	100	20	2	1995	By 1990
Poston 1-4	1949-54	216	25	4	1992	No change
Sporn 1-4	1950-52	600	26	19	1994	No change
Sporn 5	1960	450	16		1996	No change
Tanners Creek						
1-3	1951-54	495	8	24	1993	No change
4	1964	500	100		2000	No change

respectively. (Please note that AEP elected to retire certain units prematurely as being more cost effective than installing scrubbers for short remaining service lives.)

QUESTION #17

(a) Attached as Figure 4 is a breakdown of the site-specific costs for scrubber retrofit at Ohio Power Company's Gavin Plant. (AEP performed similar studies for a number of its other units in preparing its Mitchell Bill cost study.)

(b) AEP has one power plant on its system equipped with FGD equipment. Units 5 & 6 of Conesville Plant, both 425 MW, have been operating with scrubbers for approximately five and four years, respectively. The FGD design removal efficiency is 90%. The auxiliary power requirements for the system is 5.25 MW per unit, or 1.23%. This equates to a heat rate penalty of 202 mils/KWHR. A determination of the reduction in unit availabilities due to FGD malfunctions has not been made.

QUESTION #18

The current (1980 estimated percentage of fully washed coal to total coal burned by the AEP System is approximately 44.3% fully; partially washed 22.4%; unwashed 27.5%; and uneconomically washable 5.8%. The coal was washed for reasons of both generating efficiency and environmental controls. On average, it is estimated that approximately 10 to 30% of the sulfur is removed (depending upon the coal seam involved), the resultant SO_2 reductions range from 15 to 40%. The reason that resultant SO_2 reductions are greater than pure sulfur removal reductions is that the calorific

FIGURE 4

SCRUBBER RETROFIT STUDY
ESTIMATED COSTS IN DECEMBER, 1981 DOLLARS

(In 1,000's)

	Gavin 1 & 2 (2,600 MW)
Basic Scrubber Cost	$232,823
Site Specific	
Waste Handling Area	$ 29,507
Land Costs (Waste Disposal)	1,515
Haul Roads (Waste Disposal)	3,700
Disposal Site Development	5,707
Hydrobins	7,500
Metal Cleaning Pond-Relocate	800
B.A. Pond Modifications	1,834
R.R. Relocation	-----
I.D. Fans (M)	8,400
I.D. Fans (L)	937
Gas Reheat Fans (M)	800
Gas Reheat Fans (L)	260
Ductwork (M)	12,300
Ductwork (L)	3,593
Limestone Handling (M&L)	24,840
New Coal Handling System (M&L)	-----
Boiler Modifications (M&L)	7,800
Precip. Modifications (M&L)	1,300
Switch Yards (M&L)	32,000
H.V. Cable (M&L)	5,120
Electrical (M)	9,533
Electrical (L)	15,348
Electrical Building (M&L)	225
Stack and Stack Liner (M&L)	23,100
Ductwork Insulation (M&L)	1,914
Site Related Costs (M&L)	20,000
Sub-Total	$450,856
Retrofit Cost Adjustment Factor	90,171
Total	$541,027

content of the washed coal is increased from that of run-of-mine coal.

QUESTION #19

During 1980, approximately 3.5 million tons of coal out of a total of approximately 45.5 million tons were supplied from sources outside the defined ARMS region within S. 1706.

QUESTION #20

AEP has not conducted an analysis of the effectiveness of NO_x controls as an alternative to SO_2 reductions. However, as can be seen in the data presented in the answer to Question 16, NO_x emissions on the AEP system constitute about 20% of total NO_x and SO_2 emissions. Even with a high NO_x control efficiency, it appears that it would be effective as only a partial alternative to SO_2 controls.

QUESTION #21

Any answer to this question would be highly speculative and subject to unpredictable future developments, including investor behavior and state law changes.

QUESTION #22

AEP has not studied NO_x control methods to determine their reliability and cost. However, an extensive amount of material is available as a result of EPA, EPRI, and other studies of this technology.

QUESTION #23

This question cannot be answered as stated. We would have to know the quantity of mid-term emissions reductions relative to initially required reductions before being able to cost them out. Without readily ascertainable cost information, we do not know now whether our choice of reduction methods would change from those set forth in AEP's February, 1982 Mitchell Bill cost analysis.

QUESTION #24

This question calls for speculation that is inappropriate for AEP to engage in, save for the observation that broad generalities do not provide an accurate answer. We can speak authoritatively to the impact of acid rain control legislation on the AEP System and the optimal control strategy for it, but not for other utilities. To develop a specific strategy for 50 to 75 percent reduction programs, however, would require the same level of painstaking effort that we employed in preparing our Mitchell Bill study of February, 1982 and the "Acid Rain Rebuttal Survey." Please see answer to Question 4.

Please see as addenda to this letter an expanded discussion in answer to Question 3 and Figure 5, a chart setting forth various financial ratings of first mortgage bonds of AEP System operating companies. (Question 3 deals with the inclusion or exclusion of already required SO_2 control costs as incremental costs in acid rain control cost scenarios).

In concluding, AEP again emphasizes the short deadline for this letter--we have had to use a "same-day" parcel delivery service to get this letter from Columbus to Washington on June 11. Additionally, a number of the questions, notably those dealing with financial matters, are vague, speculative or unintelligible, e.g., Questions 2, 5, 8(b) and 21. Were these questions sharpened or focused, we could give you more pointed answers. We hope that this letter is satisfactory for your purposes and urge that you contact us should you have questions or need clarification.

Sincerely,

A. J. Dowd

AJD/jpw
Enclosures

ADDENDUM

QUESTION #3

On a pounds per million Btu burned basis, the AEP System has reduced SO_2 emissions by at least 15% through lower sulfur coal procurement and coal washing. Under a continuing program of comprehensive coal washing, where it can be economically beneficial to the overall cost of power generation, an additional reduction in pounds of SO_2 per million Btu burned of 10-15% will further result. Where SO_2 reductions have already been achieved, the extra cost of washed coal, above what run-of-mine coal costs were or would have been, has not been included in the calculated Mitchell Bill costs.

In those cases where washing existing sources of coal would enable meeting AEP's four reduction scenarios, (in the "Acid Rain Rebuttal Survey") the cost of it was included. In those cases where washing existing sources of coal would not enable the attainment of the reduction scenarios, it was not included in the cost estimates. It is estimated that coal washing costs of meeting any of these scenarios under existing planned programs would not amount to more than 5% of the total estimated costs involved.

Finally, in the event of capacity retirement in the normal course, replacement units will be subject to the Clean Air Act's "new source performance standards." As such, these replacement units will meet more stringent SO_2 emission limitations than the retired units. The retirement/replacement process was not factored into AEP's cost studies except when necessary to meet acid rain control law requirements.

FIGURE 5

FIRST MORTGAGE BONDS

	Moody's	S&P	Fitch	D&P	MRCM
APCo	Baa1	BBB	BBB+	8	BBB-
C&SOECo	A3	BBB+	A-	7	BBB-
I&MECo	Baa2	BBB	BBB+	9	BBB-
KPCo	A3	A	BBB	9	BBB
OPCo	Baa2	BBB+	BBB+	7	BBB-

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June 11, 1982

Mr. Curtis A. Moore
U.S. Senate Public Works and
Environmental Committee
Environmental & Public Works Committee
4204 Dirksen Senate Office Bldg.
Washington, D.C. 20510

Dear Mr. Moore:

In response to your Mailgram that I received on June 9, 1982, I have prepared this letter in order to address, at least partially, your questions concerning the cost of power plant emission reductions proposed because of concerns about acid precipitation. I appreciate the opportunity to provide information to the Committee; but your need for responses by Friday, June 11, 1982 has not allowed me time to adequately address all aspects of this very important issue. I would hope that no actions will be taken until you have received adequate information, since reasonable time should be allowed for the utility industry to prepare its inputs.

The Southern electric system is located in the Southeastern U.S. and consists of Georgia Power Company, Alabama Power Company, Gulf Power Company, Mississippi Power Company and Southern Company Services. The System currently operates over 18,500 MW of coal-fired generating capacity and expects to have over 22,000 MW of coal-fired capacity in 1991. In 1981 we burned over 40 million tons of coal. We are currently in compliance with all air quality regulations related to SO_2 and NO_x emissions. In fact, for most cases we are substantially below the allowable emission levels for SO_2.

First, I will review the position I presented to the Senate staff on June 3, 1982; and then I will attempt to answer your specific questions. Our analysis assumes that the Mitchell Bill requires a 10 million ton rollback from 1980 SO_2 emission levels for sources in 31 states (all states east of the Mississippi plus Arkansas, Minnesota, Louisiana, Iowa and Missouri) by 1992. This new SO_2 emission level will not be allowed to increase. The bill also freezes NO_x emissions at the 1980 level, although by inference additional SO_2 reductions can be made to offset NO_x growth.

Based on recent studies by a consultant (ICF) for the Edison Electric Institute, the 31 states total SO_2 emissions in 1980 resulting from using coal that exceeded the 1.2 lb/10^6Btu level was approximately 9.5 million tons. This means that the 10 million ton reduction requirement in the Mitchell Bill will require a rollback to the equivalent of less than 1.2 lb/10^6Btu fuel. The economic optimum control strategy for meeting this requirement would consist of using some mix of low sulfur coal and retrofit flue gas desulfurization (FGD) equipment. Determination of this optimum strategy is a complex problem which we are currently considering. To develop at least a rough estimate of the potential cost of the Mitchell Bill in a timely manner, it has been necessary to simplify the problem somewhat. However, we believe that the results, if properly interpreted, do give a good indication of the potential impact of this legislation on the Southern electric system and its customers.

We first calculated the cost of using low sulfur coal at actual 1981 prices to achieve the System share of the 10 million ton reduction for the 1980 coal burn rate. If this low sulfur coal (1.2 lb/10^6Btu) strategy were used for all units in the Southern electric system, fuel cost would increase annually by at least $845 million (1981$). This represents a 20-25% increase in the residential customer's bill.

As noted, the Mitchell Bill would actually establish a permanent limit on the total pounds of SO_2 and NO_x emissions for each state. In the long term, this permanent limit would diminish the economic feasibility of coal-fired power plants as an option for future generation needs. This fact results from the requirement that emissions from any new coal-fired power plant be entirely offset even though they would meet new source performance standards. Current load forecasts indicate that System 1992 emission levels will be measurably greater than the 1980 levels due to the greater utilization of existing plants and the addition of new plants. Analyzing the effect of freezing SO_2 emissions after a 10 million ton reduction is a complex problem. Because the option to use low sulfur coal would be exhausted in meeting our share of the 10 million ton reduction, FGD equipment must be used to offset emission increases due to growth. Once FGD equipment is required, then the sizing of this equipment for a particular unit would need to address not only the growth issue, but also the cost effectiveness of eliminating some of the low sulfur coal requirements at other plants caused by the 10 million ton reduction. Although the FGD equipment may not significantly increase a customer's bill above the 20-25% estimate, it will significantly increase the System's capital requirements in the late 1980's. For example, requiring 9600 MW (approximately 50% of current coal-fired capacity) of FGD equipment in this period would require at least $2.5 billion (1981$) in additional capital investment. The freezing of NO_x emissions would only exacerbate the problem. In either case (the use of FGD or low sulfur coal) we do not know how we could raise such substantial amounts of money and still maintain our planned System expansion to meet the future electricity needs of our service area.

Many factors which could cause substantial increases in these costs have not been included in these considerations. The most critical factor would be the coal market disruptions which would occur as a result of the increased demand for low sulfur coal. Other key factors are availability of capital, cost of electrostatic precipitator upgrades, unforeseen FGD waste disposal impacts, coal distribution costs, coal contract cancellations, and utility requirement to offset industrial NO_x and SO_2 growth. In addition, if an FGD requirement similar to the 9600 MW level were required, replacement power in excess of 250 MW of new generation, which has not been included in the cost estimates, would be required.

Our greatest concern still remains: there is no demonstrated benefit to this form of emission control strategy. Because of the scientific uncertainty about the relationship of SO_2 or NO_x emissions to acid rain, there is no way to determine, based on the current state of knowledge, if acid rain would be ameliorated to the extent asserted by the sponsors of the bills similar to the Mitchell Bill. It is impossible to quantify the benefits which could result if such legislation is enacted. The available scientific evidence indicates that there is not a linear relationship between SO_2 and acid rain and that other pollutants from urban sources appear to set limits on the rate of acidity production. Consequently, while the mandated reductions in SO_2 and NO_x emissions might have some effect on the acidity of rain, the actual extent of that effect is unclear.

Our preliminary attempt at answering your questions is as follows:

1A We do not have the CBO Appendix.

1B We assume that 9600 MW of FGD retrofit would be required to meet our share of the 10 million ton reduction and would partially offset the SO_2 growth requirements due to increased utilization of existing units and the addition of new units. No offset for NO_x growth was included, however, we now feel this component may be substantial.

The methodology used to estimate FGD retrofit costs is contained in an EPA funded study - Ball, J.G. and W.R. Menzies. Flue Gas Desulfurization Cost Estimates for Acid Rain Studies: Volume I: Technical Report, Radian Corporation, DCN 81-203-001-12-23, September 1981. (Draft)

This report presents cost data for FGD systems installed at new power plants as a function of the plant size and also includes a recommendation for the use of site specific retrofit factors to convert to retrofit scrubber cost estimates. Base FGD cost data ranged from $164/KW (1980$) for 880 MW unit to $324/KW for a 100 MW unit. As illustrated in Attachment 1, these cost differences are related to the economies of scale. The retrofit factors by which these base costs are multiplied represent first estimates of the complexities of putting FGD systems on existing sites where space limitations, waste disposal problems, and other constraints must be considered. These factors ranged from 1.1 to 1.4 (the normal range recommended in the report), and resulted in FGD costs ranging from $181/KW to $356/KW. I personally believe that limiting the retrofit factor to no more than 1.4 results in several of these estimates being low by as much as 50%; but it would take detailed site by site engineering studies to justify my concern.

2 Our analyses have not addressed this issue, but based upon an understanding of the factors involved, we would expect the increases in electric rates to remain relatively constant at least through the year 2000.

3 No. We are currently in compliance with all state and federal regulations for SO_2 and NO_x. In fact we are in most cases substantially below the allowed emission levels for SO_2. No unit retirements were considered in our analyses.

4A When just considering the 1980 tonnage reduction, a 20% reduction in our requirement would lead to approximately a 20% reduction in our cost estimate. However, a major uncertainty in our cost estimates is related to how we offset the anticipated growth of SO_2 and NO_x emissions from 1980 levels. We are also concerned as to how non-utility boiler growth will be treated. We believe that these cost uncertainties, along with those listed on pg. 3 (such as coal market disruptions), will cause our current cost estimates to rise. Elimination of the 1980 freezes on NO_x and SO_2 and/or exemption of NSPS units should also be considered as changes.

4B See 4A

4C Data are currently not available but it would obviously reduce each cost. However, major cost uncertainties listed on pg. 3 make exact calculations difficult.

5 Analysis is not available, but sooner or later the public will pay the true cost.

6 Will submit later.

7 No time to obtain answer. Will submit later.

8A Regulatory treatment of CWIP for the Southern electric system operating companies varies from state to state; but, with one exception that covers less than one percent of system CWIP, it is either not included in the rate base, or its inclusion is effectively offset by the inclusion of AFUDC in income. At the end of 1981, CWIP accounted for 17% of net plant investment and net AFUDC accounted for 42% of net income. Our present Standard & Poors bond ratings are:

Alabama Power Company	BBB-
Georgia Power Company	BBB+
Gulf Power Company	A+
Mississippi Power Company	A

Alabama Power and Georgia Power together account for about 87% of the Southern electric system, and thus their bond ratings are much more indicative of the overall credit rating of the System.

8B If AFUDC were treated appropriately, the inclusion of CWIP in the rate base would, in principle, change the period affected by increased rates but would not change the total present worth of the increased rates. As a practical matter, however, the inclusion of CWIP in rate base would improve cash flow and reduce AFUDC, thus improving the quality of earnings and tending to reduce the cost of capital. Actual regulatory treatments of AFUDC vary, but this principle should still apply.

It should be noted that while inclusion in the rate base of CWIP for pollution control equipment would be a step in the right direction, it would do little to offset the direct effect of the additional costs.

9 No time to accumulate details.

10 Sixty-five percent of our total pollution control equipment expenses have been financed with pollution control bonds.

11 Pollution control bond interest rates have been about three percentage points less than interest rates for the same company's first mortgage bonds.

12 No time to develop answer.

13 The $850 million per year cost given above for S1706 may be compared to total system revenue of $4.1 billion at the same time (1980) and in the same year dollars (1981).

14 Our load growth forecasts reflect average growth rates of 3.1% per year from 1982 to 1990 and 2.8% per year from 1990 to 2000. Our reserve margins are projected to be 34% in 1982 and 22% in both 1990 and 2000.

15 No time to develop answer.

16 No unit retirements were considered in our analysis.

17A Attached are copies of pages from the previously referenced draft scrubber report summarizing the assumptions used (including spare equipment) and giving a breakdown of capital and operating costs.

17B We do not have any operating FGD systems.

18 In 1981 approximately 50% of the 40 million tons of coal we purchased was washed. Our coals range in sulfur content from 0.6% sulfur to the order of 3.0% sulfur. This coal is washed by the suppliers in order to assure that they meet our tight fuel specifications (reduce ash content). The unwashed coal we purchase met

similar specifications without the need for washing. It is our feeling, for the range of sulfur contents in the coals we purchase, that less than 10% of the sulfur is removed. Mandatory coal washing is not felt to be a cost effective way for us to reduce emissions. To wash all of our coal would require an estimated $135 million (1980$) for coal washing equipment and an additional $58 million/year in operating costs.

19 In 1981 the Southern electric system purchased over 40 million tons of coal. The approximate breakdown of what states the coal came from is

System Coal Sources:

Alabama	35
Kentucky	33
Indiana	11
Illinois	10
Western	4
Tennessee	3
Foreign	3
Other	1
	100%

Therefore, approximately 7% comes from outside the ARMS region.

20 We feel that NO_x control modifications to existing units can cause a whole host of operating and boiler maintenance problems. For example, boiler tube wastage, plant derating and risk of boiler explosions could be expected. In addition, our bigger, newer units are relatively low NO_x emitters when compared to the NSPS. Therefore, any reductions would need to come from older, smaller units; and this reduction would not be adequate for the major reductions required. In light of our concerns about operational and boiler maintenance, we do not feel that NO_x reduction would be cost effective.

We will submit more detailed data if needed.

21 This question is identical to question 8B.

22 Documentation will be submitted later.

23 Opening of new low sulfur coal mines and/or installing FGD systems will require some phasing in over time. However, the imposition of a 5 year goal could do nothing but increase the cost since investments would need to be made sooner and in some cases construction would be required at an accelerated pace. Also, it might alter the orderly development of new coal sources and require more cancellations of current coal contracts.

24 Since the details of implementation and the defining of environmental measures to illustrate that some benefit was produced have not been developed, there is no way to define an efficient means of making this huge investment.

25 Will submit answer later.

I would like to thank you again for this opportunity to provide information. Please do not hesitate to call me at (205)870-6325 if you would like to discuss this further.

Sincerely,

Charles H Goodman

Charles H. Goodman

am

Attachment

cc/att: American Electric Power Service Corp.
A. J. Dowd

Edison Electric Institute
T. Brand

Hunton & Williams
G. C. Freeman
H. V. Nickel

Southern Company Services, Inc.
P. C. Bailey
R. H. Chastain

ATTACHMENT 1

TABLE 2.1.2-2 TVA UTILITY BOILER WET LIMESTONE FGD SYSTEM DESIGN SCOPE

- Costs are for new limestone FGD systems applied to new utility boilers.
- Capital investment is expressed in 1980$.
- Coal contains 3.36 percent sulfur and has a heat content of 11,700 Btu/lb.
- SO_2 removal efficiency in the scrubber is 90 percent.
- Scrubber redundancy:

Size, MWe	100	250	500	1000
Operating absorbers	1	2	4	8
Spare absorbers	1	1	1	2

- Equipment components included in the design:
  - limestone handling and preparation
  - turbulent contact absorbers and associated process equipment
  - stack gas reheaters
  - induced draft (I.D.) fans and ductwork
  - pumps for slurry transport to pond and supernatant liquor return
- Onsite pond construction to meet RCRA requirements is included. Thickeners and vacuum filters are not included.
- Particulate matter control equipment is not included.
- Heat rate is 9500 Btu/KWH for all plants.

Source - Ball, J.G. and W.R. Menzies. Flue Gas Desulfurization Cost Estimates for Acid Rain Studies: Volume I: Technical Report, Radian Corporation, DCN 81-203-001-12-23, September 1981.

TABLE 1.2.1-3 UTILITY BOILER LIMESTONE FGD SYSTEM CAPITAL INVESTMENT (1980$)

	Capital Investment,* 10^3 $			
Utility Boiler Capacity MWe	100	250	500	1,000
Boiler Heat Input** (10^6 Btu/hr)	1,000	2,500	5,000	10,000
Direct Investment				
Raw Materials Handling	1,738	1,875	3,844	4,541
SO_2 Scrubbing	9,399	16,070	26,764	53,272
Waste Disposal	5,013	8,859	14,058	22,743
Total Direct Investment (TDI)	16,149	26,805	44,666	80,556
Indirect Investment (II)				
Engr. Design & Supv. plus Architectural & Engr. (A&E)	1,453	2,412	4,020	7,250
Construction Expenses	2,584	4,289	7,147	12,889
Contractor Fees	807	1,340	2,233	4,028
Contingency	4,199	6,969	11,613	20,945
Fixed Investment (TDI + II)	25,192	41,816	69,679	125,667
Other Capital Requirements				
Startup & Modifications	1,938	3,217	5,360	9,667
Interest During Construction	3,779	6,272	10,452	18,850
Land	634	1,247	2,107	3,573
Working Capital	820	1,388	2,349	4,270
Total Capital Investment (TCI)***	32,363	53,932	89,947	162,027
$\$/KW_e$	323.6	215.7	179.9	162.0
$10^3\$/10^6$ Btu/hr**	32.4	21.6	18.0	16.2

*Refer to Tables 2.1.2-1 and 2.1.2-2 for bases.

**Assumes 10,000 Btu/kwh

***TCI = TDI + II + Other Capital Requirements.

Source - Ball, J.G. and W.R. Menzies. Flue Gas Desulfurization Cost Estimates for Acid Rain Studies: Volume I: Technical Report, Radian Corporation, DCN 81-203-001-12-23, September 1981.

TABLE 1.2.1-4 UTILITY BOILER LIMESTONE FGD SYSTEM FIRST YEAR OPERATING AND MAINTENANCE COSTS (1981$)

		Annual O&M Cost*, 10^3 $/Yr			
Boiler Capacity	MWe	100	250	500	1,000
Boiler Heat Input** (10^6 Btu/hr)		1,000	2,500	5,000	10,000
Direct Costs					
Raw Material					
Limestone		174	436	872	1,744
Conversion Costs					
Operating Labor & Supervision		172	260	356	486
Utilities					
Process Water		3	9	18	38
Electricity		264	604	1,201	2,343
Steam		166	414	829	1,657
Maintenance Labor & Materials		1,109	1,785	2,970	5,428
Analyses		52	52	78	104
TOTAL DIRECT COSTS		1,940	3,560	6,324	11,800
Indirect Costs					
Overheads					
Plant & Administrative		800	1,258	2,042	3,611
Total First Year O&M Costs***		2,740	4,818	8,366	15,411
Mills/Kwh		5.79	4.07	3.53	3.26
$/$10^6$ Btu****		0.58	0.41	0.35	0.33

*Refer to Tables 2.1.2-1, 2.1.2-2, and 2.1.3-1 for bases.

**Assumes 10,000 Btu/Kwh.

***Direct plus indirect costs.

****Based on Boiler heat input.

Source - Ball, J.G. and W.R. Menzies. Flue Gas Desulfurization Cost Estimates for Acid Rain Studies: Volume I: Technical Report, Radian Corporation, DCN 81-203-001-12-23, September 1981.

PUBLIC
SERVICE
INDIANA

June 14, 1982

Curtis A. Moore, Counsel
Environment and Public Works Committee
4204 Dirksen Senate Office Building
Washington, D.C. 20510

Dear Mr. Moore:

In response to your mailgram dated June 8, 1982, we have provided responses to questions 1(B), 8, 13, 16, 17, 18, 21 and 23 attached as Exhibit I. Responses to the remaining questions will be sent in the near future.

Very truly yours,

S. A. Ali

S. A. Ali
Manager, Environmental
Programs

SAA:dls

Attachment

cc: J. H. Pennington, Public Service Indiana
G. C. Freeman, Jr., Hunton & Williams
H. V. Nickel, Hunton & Williams
T. Brand, EEI
R. A. Beck, EEI

1000 East Main Street, Plainfield, Indiana 46168 317 .. 839 . 9611

EXHIBIT I

PUBLIC SERVICE INDIANA
RESPONSES TO QUESTIONS FROM COMMITTEE STAFF OF U.S. SENATE ENVIRONMENT & PUBLIC WORKS COMMITTEE

Question 1-B (Mid-1981 dollars)

Total System: 8 scrubber units for a total of 5190 MW
Total cost = $1 to $1.35 billion
Average cost/kw = $193 to $260

Many factors influence the cost of retrofitting scrubbers onto existing units. In some instances coal yards and substations may need to be relocated to make physical space. For some units, superstructures will be required to erect a facility above flood-plain levels. The availability of sludge disposal area will effect unit costs. The amount of redundant or spare capacity planned for each unit will differ dependent on unit age and expected load factors. PSI engineering estimates for individual unit costs were ranged to take many of these factors into consideration.

Question 8-A

The Public Service Commission of Indiana (jurisdiction over approximately 85% of 1981 revenues) does not allow the inclusion of any portion of construction work in progress (CWIP) in rate base in determining utility rates. The Federal Energy Regulatory Agency (jurisdiction over approximately 15% of 1981 revenues) permits only the inclusion of pollution control equipment in rate base while under construction.

As of December 31, 1981, the Company had $1.4 billion of construction work in progress and $120 million of nuclear fuel. AFUDC represented approximately 15% of the total. Effective January 1, 1982, the Company adopted a 12.5% semi-annually compounded AFUDC rate (previously a 9.5% simple interest rate was used), which reflects the increased cost of money being incurred. As a result, the impact of AFUDC on the Company's current construction program in 1982 and subsequent years in dramatic. For instance, of the total Marble Hill (PSI's nuclear plant currently under construction) project cost, AFUDC represents approximately 46% of the total $4.3 billion cost.

In November 1981, the Company's outstanding first mortgage bonds and preferred stock ratings were lowered from a double "AA" to single "A" category.

Question 8-B

Inclusion of CWIP in rate base would reduce construction costs by the AFUDC portion of any project. When the analysis was conducted in 1981 AFUDC accounted for 10.6% of the projected cost. Recent changes increase the projected AFUDC to over 16%.

Question 13

The Company estimates that in 1990 approximately $400 million (mid-1981 dollars) would be required to support annual operating and capital costs if retrofit scrubbers were required. Rate increases of 50% or more are projected as a result of S.1706.

Question 16

Plant	Age Years	Capacity	Permitted SO_2 Rates #/10^6 BTU	Permitted NO_x Rates
Gibson (3-4)	3-4	1,352	5.1	0.7 lbs/10^6BTU
Gibson (1-2)	5-6	1,352	5.1	Uncontrolled
Cayuga	10-12	1,070	6.0	Uncontrolled
Wabash River	14-29	788	4.04	Uncontrolled
Gallagher	21-24	628	6.0	Uncontrolled
Edwardsport	31-38	176	6.0	Uncontrolled
Noblesville	32	111	6.0	Uncontrolled

Our analysis is based on 85% reduction of actual emissions of SO_2. Scrubbers are considered for all but the last two stations. These two peaking stations are assumed to utilize low sulfur coal. NO_x reduction was not found to be cost effective for existing units.

The retirement dates of all units remains the same with or without emission reduction similar to S.1706. Retirement dates have not been established; however, the Edwardsport and Noblesville stations are anticipated to be retired in the later half of the 1990's.

Question 17-A

The amount of "spare" capacity built into cost estimates was based upon several factors including the age of the facility, the number of boilers the unit will be serving and expected load factors. Our estimate includes about 25% spare capacity for the Cayuga and Gibson stations and no spare capacity at the Wabash River station.

Question 17-B

The Company's Gibson Unit 5 to be operational October 1, 1982 will be the first scrubber on the PSI system. The design percent reduction is expected to be over 80%.

Question 18

We are currently burning over 75% washed coal. It is washed for both operational improvement and to meet environmental regulations. The actual washing is done by the coal suppliers. A rule of thumb for conventional coal washing of Illinois basin coal is that up to 25% sulfur reduction is achieved.

Question 21

See 8-B.

Question 23

If the State allows a system bubble for interim goals the capital portion of the cost would not increase but the annualized cost, due to earlier operation and maintenance, would increase. However, if individual plants were required to meet interim goals, the overall cost would increase. In either case the earlier carrying charges for capital expenditures would increase the overall cost of compliance with the legislation. PSI would plan to use the same compliance methods to achieve SO_2 reduction as presently analyzed for S.1706.

PUBLIC
SERVICE
INDIANA

June 23, 1982

Curtis A. Moore, Counsel
U.S. Senate Environment and Public Works Committee
4204 Dirksen Senate Office Building
Washington, D.C. 20510

Dear Mr. Moore:

Attached as Exhibit I are the responses to questions contained in your June 8, 1982 mailgram directed to me and also to Mr. J. H. Pennington, Vice President Financial Operations.

Very truly yours,

S. A. Ali

S. A. Ali
Manager, Environmental Programs

SAA:laf

Attachment

cc: J. H. Pennington
J. Burnam, Senator Lugar's Office
G. C. Freeman, Jr., Hunton & Williams
H. V. Nickel, Hunton & Williams
T. Brand, EEI
R. A. Beck, EEI

1000 East Main Street, Plainfield, Indiana 46168 317 .. 839 . 9611

EXHIBIT I

PUBLIC SERVICE INDIANA
RESPONSES TO QUESTIONS FROM COMMITTEE STAFF OF
U.S. SENATE ENVIRONMENT & PUBLIC WORKS COMMITTEE

Question - 1A

Our estimates of scrubber costs do not vary by more than 50% from the CBO estimates. Our historical coal cost by SO_2 emission limit on an as received basis is as follows:

	Station	SO_2 Limit #/10^6BTU	Cost/ Ton
1981*	Gibson	5.1	$31.04
	Cayuga	6.0	23.68
	Wabash River Station	4.04	29.46
	Gallagher	6.0	23.76
	Edwardsport	6.0	21.06
	Noblesville	6.0	28.00
1980	Gibson	5.8	$26.81
	Cayuga	6.0	18.87
	Wabash River Station	4.04	24.50
	Gallagher	6.0	22.44
	Edwardsport	6.0	19.83
	Noblesville	6.0	25.58

*There was a coal strike in 1981.

Question - 1B (Mid-1981 dollars)

Total System: 8 scrubber units for a total of 5190 MW
Total Cost = $1 to $1.35 billion
Average cost/kw = $193 to $260

Many factors influence the cost of retrofitting scrubbers onto existing units. In some instances coal yards and substations may need to be relocated to make physical space. For some units, superstructures will be required to erect a facility above floodplain levels. The availability of sludge disposal area will affect unit costs. The amount of redundant or spare capacity planned for each unit will differ dependent on unit age and expected load factors. PSI engineering estimates for individual unit costs were ranged to take many of these factors into consideration.

Question - 2

We have not conducted a detailed analysis, however, it is our expectation that increasing maintenance and operating costs due to the age of the equipment and inflation will be greater than the depreciating capital portion of the project and that required revenues would increase. Percentages may decline, but cost per Kwh would continue to increase.

Question - 3

PSI is currently required to make no further reductions in SO_2 emissions and is in compliance with Indiana's State Implementation Plan (SIP).

Question - 4 (A,B & C)

If a system wide bubble is allowed to meet the emission reductions, PSI would meet its required reduction by installing scrubbers on a portion of its unscrubbed capacity. The total capital costs, electricity rates and annual costs would be reduced in direct proportion to the required reduction. The $/ton removed would remain about constant. If individual stations were required to meet these percentages, the reductions in cost would not decrease proportionally and a detailed study would be required to estimate the ratio.

Question - 5

Compliance by the Company under S.1706 of retrofitting scrubbers onto existing units with the least impact on consumer costs would be achieved by permitting construction work in progress (CWIP) in rate base. CWIP in rate base would permit the current recovery of financing costs and eliminate the Allowance for Funds Used During Construction (AFUDC) amount now included in such projects. The next least costly method to the consumer would be to raise the necessary capital by using pollution control bonds rather than using conventional and more costly methods of financing, assuming that pollution control bonds would maintain their market price advantage.

Question - 6

The carrying charge calculation includes the following components:

1. Common stock equity
2. Long term debt
3. Preferred stock
4. Property and real estate taxes
5. Insurance
6. Depreciation

Items one through three are used to determine the weighted average cost of capital used to fund construction projects. Common stock equity was assumed to be 40% of total capitalization and the cost rate used was that allowed in the most recent retail rate order which was approved June 10, 1981, before the Indiana Commission. Long term debt and preferred stock was assumed to be 50% and 10% of total capitalization, respectively. The weighted average cost of money used, reflects the forecasted cost or rate of return to be charged consumers when the projects are completed and placed in service. Pollution control notes/bonds were not considered in this evaluation.

Question - 7

The weighted average cost of capital used in this evaluation was 15.50%. The common stock equity portion of total capitalization reflected a 16.75% return on equity which was allowed in the most recent retail rate order (approved June 10, 1981) before the Indiana Commission. The Indiana Commission in such order allowed an overall rate of return of 12.19% based upon a September 30, 1980 proforma test year filing. The 15.50% reflects a forecasted weighted average cost of capital in the year 1990.

Question - 8A

The Public Service Commission of Indiana (jurisdiction over approximately 85% of 1981 revenues) does not allow the inclusion of any portion of construction work in progress (CWIP) in rate base in determining utility rates. The Federal Energy Regulatory Agency (jurisdiction over approximately 15% of 1981 revenues) generally only permits the inclusion of pollution control equipment in rate base while under construction.

As of December 31, 1981, the Company had $1.4 billion of construction work in progress and $120 million of nuclear fuel. AFUDC represented approximately 15% of the total. Effective January 1, 1982, the Company adopted a 12.5% semi-annually compounded AFUDC rate (previously a 9.5% simple interest rate was used), which reflects the increased cost of money being incurred. As a result, the impact of AFUDC on the Company's current construction program in 1982 and subsequent years is dramatic. For instance, of the total Marble Hill (PSI's nuclear plant currently under construction) project cost, AFUDC represents approximately 46% of the total $4.3 billion cost.

In November 1981, the Company's outstanding first mortgage bonds and preferred stock ratings were lowered from a double "AA" to single "A" category.

Question - 8B

Inclusion of CWIP in rate base would reduce construction costs by the AFUDC portion of any project. When the evaluation of S.1706 was conducted in 1981, AFUDC accounted for 10.6% of the project cost. Recent changes in the AFUDC rate has increased the projected AFUDC portion to over 16%.

Question - 9

Coals burned are all from local sources (Illinois basin coals) and are shipped from 7 to 130 miles. For prices refer to question 1A. Coal is received by barge, truck and rail with over 80% being received by rail. Current transportation charges range from $1 to $4 per ton with $2 per ton being the estimated average cost.

Question - 10

Eligible pollution control expenditures of a significant magnitude which warranted the sale of pollution control notes/bonds were financed with a pollution control revenues security. As of April 1982 the Company has issued the following pollution control securities:

Date	Amount 1)	Rate
December 1973	$22,000,000	5-3/4%
March 1979	5,000,000	6-5/8%
April 1982	10,000,000	12-3/8%
April 1982	35,000,000	12-3/4%

1) The total of $72,000,000 represents about 6% of total long term debt outstanding for the Company.

Question - 11

Historically, pollution control financing (heretofore non-secured notes and bonds secured by Company first mortgage bonds) for the Company has been 225 to 300 basis points less than first mortgage bonds which are secured bonds and have been the only other type of long term debt issued by the Company. If and when pollution control financing opportunities are available and less expensive than other sources of financing, then the Company intends to utilize such.

Question - 12

PSI would conduct analysis which considers fuel prices (including transportation) and availability before plant design was selected. A recently built station complying with the 1971 NSPS requirements selected Illinois basin coal in combination with scrubbing.

Question - 13

The Company estimates that in 1990 approximately $400 million (mid-1981 dollars) would be required to support annual operating and capital costs if retrofit scrubbers were required. Rate increases of 50% or more compared to current rate levels are projected as a result of S.1706.

Question - 14

The Company's current peak load forecast (dated July 1981) for the period 1981-1992 projects an annual winter rate of 4.1% and summer rate of 3.5%. Annual usage during the period should increase approximately 3%. Projected reserve margins for winter peak loads during the 1981-1992 period will fluctuate as new units (Gibson Unit 5 (650 MW) - 1982, Marble Hill Unit 1 (1130 MW) - 1986 and Marble Hill Unit 2 (1130 MW) - 1987) are completed and brought onto the system. During the period immediately prior to completion of the Marble Hill units (1986-87), the Company's reserve margin should average around 40%. After both Marble Hill units have been brought on line, the margin should average about 50% during late 1980's and early 1990's.

Question - 15

PSI would continue with its current coal contracts and would purchase Illinois basin coal where possible. It is anticipated that the two older coal-fired peaking stations would burn low sulfur coal.

Question - 16

Plant	Age Years	Capacity	Permitted SO_2 Rates #/10^6BTU	Permitted NO_x Rates
Gibson (3-4)	3-4	1,352	5.1	0.7 lbs/10^6BTU
Gibson (1-2)	5-6	1,352	5.1	Uncontrolled
Cayuga	10-12	1,070	6.0	Uncontrolled
Wabash River	14-29	788	4.04	Uncontrolled
Gallagher	21-24	628	6.0	Uncontrolled
Edwardsport	31-38	176	6.0	Uncontrolled
Noblesville	32	111	6.0	Uncontrolled

Our analysis is based on 85% reduction of actual emissions of SO_2. Scrubbers are considered for all but the Edwardsport and Noblesville stations. These two peaking stations are assumed to utilize low sulfur coal. NO_x reduction was not found to be cost effective for existing units.

The retirement dates of all units remains the same with or without emissions reduction similar to S.1706. Retirement dates have not been established; however, the Edwardsport and Noblesville stations are anticipated to be retired in the latter half of the 1990's.

Question - 17A

The amount of "spare" capacity built into cost estimates was based upon several factors including the age of the facility, the number of boilers the unit will be serving and expected load factors. Our estimate includes about 25% spare capacity for the Cayuga and Gibson Stations and no spare capacity at the Wabash River station.

Question - 17B

The Company's Gibson Unit 5 to be operational October 1, 1982 will utilize the first scrubber on the PSI system. The design percent reduction is expected to be about 86 percent.

Question - 18

We are currently burning over 75% washed coal. It is washed for both operational improvement and to meet environmental regulations. The actual washing is done by the coal suppliers. A rule of thumb for conventional coal washing of Illinois basin coal is that up to 25% sulfur reduction is achieved.

Question - 19

None.

Question - 20

NO_x control on existing plants was considered and was not found to be as cost effective as SO_2 removal with the use of scrubbers.

Question - 21

See 8B.

Question - 22

Not available.

Question - 23

If the State allows a system bubble for interim goals the capital portion of the cost would not significantly change but the annualized cost, due to earlier operation and maintenance, would increase. However, if individual plants were required to meet interim goals, the overall cost would increase. With or without the system bubble concept the earlier capital expenditures would increase the overall cost of compliance with the legislation to the PSI consumer. PSI would plan to use the same compliance methods to achieve SO_2 reduction as presently analyzed for S.1706. Regardless of the time period or method of compliance implemented, Indiana ratepayers would be forced to support a non-productive expenditure from which they will receive no benefit versus an expenditure to support their electricity demands and to maintain system reliability.

Question - 24

Allowing individual companies the most flexibility in meeting their required reductions through a system bubble approach.

Question - 25

The percentage of electric power transferred to other electric utilities (primarily "pool" commitments) during the last five years has averaged about 11%. Presently the Company has no generating facilities which are owned or operated with other utilities.

Specific questions for Mr. J. H. Pennington

1. The Company's current construction program is predicated upon system demand and reliability. Such costs impact to the customer reflect replacement of aged facilities, growth and continued and improvement of system reliability.

   Senate Bill 1706 would cause Indiana ratepayers to incur costs associated with a non-productive capital expenditure. Such costs would not improve system reliability nor satisfy increased demand.

   Therefore, to compare the cost impact upon customers of financing nuclear projects or any new capacity versus coal-fired scrubber plant additions is not the issue. The issue to be addressed is whether or not expenditures for coal-fired scrubber plant additions are economically justified without substantially more research.

2. The Indiana Commission granted the Company in their last retail rate order an overall rate of return of 12.19% based on embedded costs. Adjusting such amount for the tax impact of the equity portion (approximately 6%), and including the property tax (approximately 2.4%), and insurance and depreciation components (approximately 3.5%), the overall levelized fixed charge rate is well above 20%. Considering the inflationary pressures on related plant costs and the impact of refinancing current embedded costs (the Company currently has over $600 million of long term debt outstanding with interest rates under 9%), the likelihood of the levelized fixed charge rate dropping below 20% is very slight. In addition, costs of new money are now in the 15.5% to 16% range.

IPL
INDIANAPOLIS POWER & LIGHT COMPANY

June 11, 1982

Mr. Curtis A. Moore
Associate Counsel
Committee on Environment &
Public Works
4204 Dirksen Senate Office Building
Washington, D. C. 20227

Dear Mr. Moore:

In response to your mailgram request which Indianapolis Power & Light Company received on June 9, 1982 I have attempted to respond to those questions on which priority was placed. The responses, enumerated consistent with your mailing, are enclosed.

Responses to the remaining questions will be developed, to the extent possible, and submitted to you at a later date. I trust this is adequate for your immediate needs.

Sincerely,

INDIANAPOLIS POWER & LIGHT COMPANY

Terry M. Hogan
for Robert A. McKnight
Chief Environmental Engineer

RAM:sk

25 MONUMENT CIRCLE · P.O. BOX 1988B · INDIANAPOLIS, INDIANA 46206 · (317) 261-8261

IPL Response to Mailgram Dated June 8, 1982

1B. The cost for retrofitting of scrubbers would be an estimated $240/KW (1981 dollars) as previously indicated or approximately $216/KW (1980 dollars).

8.A(1) CWIP is not in the current rate base.

(2) There is no AFUDC in "current assets". The AFUDC portion for utility plant at original cost is not readily available. The AFUDC rate for 1983 through 1986 is 12.2%.

(3) IPL's current bond rating is AA Standard & Poor's and AA2 Moody's.

8B It is estimated that AFUDC is about 15% of the $240/KW (1981 dollars) retrofit scrubber costs.

13. It has been projected that in 1990 an additional revenue requirement of $356,300,000 would exist due to S 1706, which represents 49% of anticipated 1990 revenue (all in 1990 dollars). Prior to 1990, it would be a function of phase-in requirements which, to date, are unavailable. In subsequent years, a portion of the projection would be subject to escalation.

16. IPL Generation Information Requested In Question 16.

Facility/Unit	Size MW	Year Installed	Current SO_2 Max. Allowable Emission Rate lbs. SO_2/MMBTU	Reduction SO_2 Max. Allowable Emission Rate lb. SO_2/MMBTU Used in Analysis	NOx Emission Rate
Petersburg					
Unit 1	255	1967	6.0	1.2	NA
Unit 2	455	1969	6.0	1.2	NA
Unit 3	515	1977	1.2	1.2	NA
Unit 4	515	1986	1.2	1.2	NA
H. T. Pritchard					
Unit 1	48	1949	0.35	0.35	NA
Unit 2	48	1950	0.35	0.35	NA
Unit 3	48	1951	6.0	1.2	NA
Unit 4	69	1953	6.0	1.2	NA
Unit 5	69	1953	6.0	1.2	NA
Unit 6	109	1956	6.0	1.2	NA
E. W. Stout					
Unit 1	38	1931	0.35	0.35	NA
Unit 2	38	1931	0.35	0.35	NA
Unit 3	44	1942	0.35	0.35	NA
Unit 4	44	1947	0.35	0.35	NA
Unit 5	109	1958	5.3	1.2	NA
Unit 6	109	1961	5.3	1.2	NA
Unit 7	440	1973	5.3	1.2	NA
C.C. Perry	(Steam M lbs/hr)				
Boiler 11&12	500	1938	6.0	1.2	NA
Boiler 13&14	600	1946/47	6.0	1.2	NA
Boiler 15&16	450	1953	6.0	1.2	NA
Boiler 17&18	340	1975/73	0.35	0.35	NA
Boiler W.17&18	300	1950	6.0	1.2	NA

Note: No retirements of units are currently established with or without a reduction program similar to S. 1706.

TMH 6-10-82

17A. The estimate does include sufficient redundancy in equipment to attain reasonable and necessary scrubber availability.

The IPL cost estimates for the two FGD systems which the company would backfit on existing units in 1981 dollars would total $240. per KW capacity with operation and maintenance in current dollars at approximately $6/ton of coal. These costs include cost for the FGD system, the sludge treatment system and landfill requirements which would be imposed on these plants. They reflect somewhat higher costs than would be expected on new units because of the space restrictions and other constraints outlined in our presentation. Since the construction of this equipment would not be done immediately but would have its major cash flow in the year 1990 these costs were escalated to reflect an inflation factor of approximately 10% simple interest per year. This cost should reflect all costs associated with the FGD system including the capacity loss penalty due to the reliability loss and power consumption by the FGD system itself.

17B. The anticipated scrubbers for retrofit would be required to achieve an approximate 80% removal efficiency. IPL's current operating scrubber is approximately five years old and has a design removal efficiency of approximately 86%. The operation of the scrubber and related required equipment constitutes a use of approximately 5% of the unit's total generating capacity.

18. Approximately 80% of the coal utilized is washed and generally represents coal purchased from larger mine operations. The remaining is unwashed and reflects that coal generally purchased from smaller mines. Small mines do not have sufficient coal reserves on which they can justify a preparation plant. The coal is washed to improve its quality and to reduce ash content. The percentage of sulfur changed by washing varies with the type of coal. It is estimated that the percent sulfur content may be reduced from less than 0.25% for lower sulfur coal to perhaps as high as 0.5% for higher sulfur coal. For example, 4% sulfur coal might be reduced to a range of 3.5 to 3.75% sulfur coal. The effects of washing is heavily influenced by the specific coal characteristics, however. A large portion of the unwashed coal represents coal which would show insufficiently improved analysis to justify the cost.

21. See 8(B)

23. Without detailed consideration and analysis, which time does not allow, it appears evident that a mid-term emissions limitation would increase long-term reduction costs. Whether it would affect the choice of reduction methods depends on, in part, the mid-term emission level imposed. A significant emission level reduction could impose the necessity to burn low sulfur coal where scrubber installation might otherwise be planned. Such a change would, of course, increase costs as the previous analysis was based on the most practical and economical solutions reasonably available, based on currently available information.

The mid-term emission limitation, by cutting the response time in half, could have a pronounced market effect for both low sulfur fuel and FGD scrubbers. Given the high demand on the market, substantial increases in costs could occur, assuming vendors could meet the demands. Similarly, the mid-term emission limitation would shift the cash flow for compliance activities earlier, which would tend to increase the present worth of revenue requirements.

It is anticipated that mid-term emission limitation imposition would increase costs by requiring expeditious but less economical compliance methods. It could further limit options available to utilities for achieving compliance. As such, the mid-term emission limitations pose an even greater potential burden to IPL and its customers.

OHIO EDISON
The Energy Makers

76 South Main St.
Akron, Ohio 44308
216-384-5100

June 21, 1982

Mr. Curtis Moore
Senate Committee on Environment
and Public Works
4204 Dirksen Senate Office Building
Washington, DC 20510

Dear Mr. Moore:

Attached are our answers to the questions you forwarded regarding the cost of complying with proposed "acid rain" legislation.

I'd like to emphasize that figures represent orders of magnitude rather than precise estimates developed from detailed studies.

In actual practice, when an electric company contemplates a construction program involving major expenditures, the planning process involves months of effort and costs in the hundreds of thousands of dollars.

If this seems exaggerated, I would refer you to a study prepared for Ohio Edison in 1976-77 by our engineering consultants that served as the basic reference document for our current environmental programs. It took about six months to prepare and cost approximately $200,000. In point of fact, many of the figures we are citing today in giving the approximate cost of various proposals for additional controls are extrapolated from the study completed in 1977.

I believe that all of the compliance cost estimates you are studying should be treated with a great deal of caution. When a person attempts to forecast and quantify such things as coal market behavior, equipment costs and degrees of cooperation among government jurisdictions, the results will vary significantly on the basis of the analyst's opinions.

Very truly yours,

C.V. Runyon /Rw

Charles V. Runyon, P.E.
Manager, Environmental and
Special Projects Department

REH:ef
Att.

QUESTION:

1. (A) IF YOUR ESTIMATE OF SCRUBBER COSTS VARIED BY MORE THAN 50 PERCENT FROM THE ESTIMATES IN THE CBO APPENDIX, PLEASE EXPLAIN WHY. IF YOUR ESTIMATED COSTS FOR CLEANER FUELS VARY BY MORE THAN 30 PERCENT, AGAIN EXPLAIN. ALSO PLEASE PROVIDE HISTORICAL FUEL PRICES (BY SO_2 EMISSION RATE) PAID BY YOUR UTILITY.

ANSWER:

1. (A) Our FGD (scrubber) estimate varied by more than 50% due to:

   1) Particularly at our largest Ohio plant, there is an extreme cost penalty associated with retrofitting FGD to a small, cramped plant site which already has experienced a retrofit of pollution control equipment which was placed on a deck over a highway adjacent to the Ohio River.

   2) Size of generating units on our system range from 25 MW to 600 MW resulting in increased costs for smaller plants compared to large scale FGD installation contemplated for 500 MW units.

We do not feel we have enough information for comparison of our estimated costs for lower sulfur fuel. Low sulfur coal costs about $10 to $15 more per ton than high sulfur coal in today's market, and would be subject to substantial inflation, increasing as the market becomes more constrained.

QUESTION:

1. (B) REGARDING SCRUBBER CAPITAL COSTS, PLEASE PROVIDE ESTIMATES OF DOLLARS-PER-KILOWATT FOR EACH UNIT TO BE RETROFITTED.

ANSWER:

1. (B) The estimates we have used to derive scrubber capital costs were developed by Commonwealth Associates, Inc. for the Ohio Edison Co. in 1977. We used an average cost per kilowatt to estimate scrubbers to all our units. The average cost per kilowatt was approximately $371. while the low was represented by the figure $348. and the high $373.

OHIO EDISON COAL QUANTITY AND COST DATA - 1980
(Currently Existing Plants)

PLANT Sammis 1-4

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	32.75	33631
	35.90	2911
	37.44	898
	35.96	115302
	36.63	4028
	36.94	53528
	36.24	277164
	35.27	5439
	38.44	157260
	41.35	425987
	41.23	39411
	38.31	231101
	41.19	96979
	42.86	399603
	32.33	1555
	38.61	(a)(6993
Total Truck	31.21	26638
Total Barge	39.73	1811164
Total Plant	39.61	1837802

PLANT Sammis 5-7

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	16.67	29247
	17.82	59632
	17.09	256972
	19.07	27782
	22.59	2194
	22.57	2793
	21.23	564
	23.51	2576
	24.50	3570
	27.00	1277
	28.41	49002
	30.40	29968
	30.84	76654
	32.17	403552
	31.42	117682
	31.88	96242
	31.55	75476
	32.06	138957
	32.93	165624
	32.57	204593
	35.06	150449
	37.08	1121105
	35.71	843
	36.57	8573
	40.76	2656
	38.41	486
	37.89	13952
	40.27	3598
	40.42	2730
	31.16	1295
	35.21	48
	38.61	(a)6993
Total Truck	29.29	1901799
Total Barge	37.39	1155286
Total Plant	32.45	3057085
		–
Total Plant	35.07	4894887

(a) Inter-supply transfer.

OHIO EDISON COAL QUANTITY AND COST DATA - 1980
(Currently Existing Plants)

PLANT Mad River

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	30.85	7933
	30.55	3483
	32.00	2979
	34.13	578
	36.37	13356
	35.00	313
	36.50	10817
	37.00	1247
	35.77	609
	39.51	8907
	37.68	14091
	39.25	924
	38.14	5497
	38.21	10947
	36.50	1043
	36.40	(a)(20)
Total Truck	33.85	30334
Total Barge	37.87	52370
Total Plant	36.40	82704

PLANT Gorge

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	19.90	9364
	19.70	7971
	21.64	33053
	23.05	7285
	23.05	10284
	23.65	16893
	25.53	24799
	25.28	22899
	26.94	28919
	26.70	126
	31.52	6611
	30.00	5578
	33.97	17044
	33.70	7564
	34.04	17417
	32.50	3555
	34.22	5065
	33.00	534
	33.30	2044
Total Truck	26.58	227005

(a) Bracket indicates ordered but not delivered.

OHIO EDISON COAL QUANTITY AND COST DATA - 1980
(Currently Existing Plants)

PLANT Niles
PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	19.75	70026
	19.63	9480
	20.00	11230
	21.05	8779
	22.26	17293
	22.90	5165
	22.90	4836
	24.50	625
	30.00	36456
	30.17	29124
	31.58	76726
	31.22	59789
	34.68	13852
	33.76	31298
	33.21	10478
	35.19	114823
Total Truck	29.47	460378
Total Barge	31.03	39602
Total Plant	29.60	499980

PLANT R. E. Burger
PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	27.35	12982
	31.73	14618
	32.70	45649
	30.59	43681
	32.59	14052
	45.01	929056
Total Truck	31.72	87301
Total Barge	44.36	972737
Total Plant	43.32	1060038

PLANT Edgewater
PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	17.09	1720
	24.89	1574
	27.28	12579
	28.25	4344
	30.00	38743
	30.50	34043
	31.60	58638
	31.24	3982
	34.97	20615
	34.75	1496
	38.65	21461
	39.48	112854
	43.60	25470
	41.65	33695
	42.08	30537
Total Truck	34.21	290588
Total Barge	42.63	111163
Total Plant	36.54	401751

PLANT Toronto
PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	14.53	80854
	14.99	12866
	15.36	4628
	19.46	24935
	21.26	13353
	21.23	7400
	22.95	4477
	23.13	21177
	25.16	14078
	28.84	60567
	30.40	28934
	30.29	113383
	32.68	19826
	33.81	141
Total Truck	22.48	293236
Total Barge	30.31	113383
Total Plant	24.66	406619

QUESTION:

2. WHEN CALCULATING PERCENTAGE INCREASES IN ELECTRICITY RATES DUE TO AN ACID RAIN CONTROL PROGRAM, DO THESE PERCENTAGES REMAIN CONSTANT PAST 1990 (E.G., 2000, 2010)?

ANSWER:

2. We have not analyzed the cost impact past 1990.

QUESTION:

3. IF NO ADDITIONAL REGULATIONS ARE IMPOSED WILL YOUR UTILITY BE REDUCING EMISSIONS FROM CURRENT ACTUAL LEVELS ANYWAY (E.G., TO MEET SIP COMPLIANCE, RETIREMENT, ETC.)? WERE THE COSTS OF THESE REDUCTIONS INCLUDED IN YOUR COST ESTIMATES?

ANSWER:

3. No.

QUESTION:

4. (A) IF THE EMISSION REDUCTIONS REQUIRED BY AN ACID RAIN CONTROL PROGRAM WERE 80 PERCENT OF THE TONNAGE ASSUMED IN YOUR CALCULATIONS, BY HOW MUCH WOULD YOUR COSTS BE REDUCED (PROVIDE YOUR BEST ESTIMATE, E.G., 10 PERCENT, 25 PERCENT, 50 PERCENT REDUCTION IN COST)?

(B) IF THE EMISSION REDUCTIONS WERE 60 PERCENT OF THE TONNAGE ASSUMED?

(C) ALL OTHER THINGS BEING EQUAL, IF S. 1706 AS NOW DRAFTED REQUIRED A 5 MILLION TON SO_2 REDUCTION FROM CURRENT LEVELS RATHER THAN 10 MILLION TONS, HOW WOULD IT AFFECT KEY FACTORS SUCH AS:

-- TOTAL CAPITAL COSTS
-- $/TON REMOVED
-- ELECTRICITY RATES
-- ANNUAL COSTS.

ANSWER:

4. (A) 45%

(B) 70%

(C) Impacts would be reduced by 80%

The above estimates are "best case", based upon substantial use of out-of-state low sulfur coal. We believe this represents the most cost effective means of reducing SO_2 emissions at our plants but it may not be politically realistic. If we were prevented from using substantially more out-of-state coal, be it by law or market conditions, our reliance on scrubbing would increase.

QUESTION:

5. IF YOU WERE REQUIRED TO REDUCE EMISSIONS UNDER S. 1706, IN WHAT THREE WAYS (IN ORDER OF PRIORITY) MIGHT UTILITY COSTS OF THE CONTROL PROGRAM BE REDUCED (E.G., AUTOMATIC FUEL PRICE ADJUSTMENT CLAUSES) AND IN WHAT THREE WAYS MIGHT CONSUMER COSTS BE REDUCED.

ANSWER:

5. (A) Require less control by utilities and more by other sources;

   (B) Allow liberal trade of NOx emission reduction for SO_2 emission reduction;

   (C) Promote increased use of electricity to provide more revenue per unit of capital invested for emission control.

Reduce consumer costs in the same three ways.

QUESTION:

6. PLEASE EXPLAIN YOUR CHOICE OF THE COMPONENTS OF CARRYING CHARGES ON CAPITAL INVESTMENT. WHAT DO YOU ASSUME AS TO THE AVAILABILITY OF POLLUTION CONTROL BONDS?

ANSWER:

6. Any discussion on a series of capital expenditure projects and their related carrying costs should not be taken in isolation. This observation is especially pertinent for any capital intensive business, and specifically the electric utility industry and the Ohio Edison Company. Recognition must be given to:

   1. Our primary objective which is to continue to provide economical and highly reliable electric service to our customers (while earning for the investor a competitive return within the constraints and opportunities afforded by various regulatory and political actions and influences);
   2. The magnitude of already existing and planned expenditure programs necessary to maintain and meet our service obligations stated in (1), and;
   3. The limitations and constraints imposed upon any company by its financial health and flexibility overtime; such limitation being reflective of future economic growth expectations, influenced by both national and specific regional economic factors, and the competitive capital markets (investment alternatives) and associated risks as perceived by the investment community.

All of these factors are of course in no way stagnant and should be viewed with a prospective which provides for the flexibility necessary to respond to changes. At this time with the negative influences experienced and continuing to be experienced by the electric utility industry generally, and the Ohio Edison Company specifically, the degree of latitude needed in projecting both capital requirements and the timing as to the funding of such requirements is extremely critical. Given the above prospective and that of our Company's strained existing financial position, recognized funding requirements over the next five years and the continuing abnormal state of the financial markets, the Company presently uses a gross cost of capital rate of 17.25% to evaluate new expenditure commitments. This weighted rate reflects the incremental capital cost structured to 48% debt, 12% preferred and 40% equity. The future use of industrial revenue bonds in the financing of pollution control related projects is of course contingent upon the U.S. Treasury Department actions and proposals presently under consideration. Generally, the indications and opinions we have received on the Treasury's activities and direction would indicate much more restrictive implications on this funding source and, in several practical respects, outright elimination to some degree on their future use.

QUESTION:

8. (A) WHAT PORTION OF CWIP, IF ANY, ARE YOU ALLOWED TO PLACE IN YOUR RATE BASE? WHAT PORTION OF CURRENT ASSETS ARE AFUDC? WHAT IS YOUR PRESENT BOND-RATING?

ANSWER:

8. (A) Public Utility Commission of Ohio does not allow CWIP in rate base unless the project is 75% completed.

FERC does allow Environmental projects CWIP in rate base regardless of the % of the project completed. This is only a small percentage of revenues.

2. The estimated AFUDC balance as of 12/31/81 is $265,616,173.91.

3. See attachment for present bond ratings.

QUESTION:

8. (B) WHAT WOULD BE THE IMPACT ON PROJECTED REDUCTION COSTS OF ALLOWING CWIP FOR POLLUTION CONTROL EQUIPMENT INTO YOUR CURRENT RATE BASE?

ANSWER:

8. (B) If the CWIP is permited in rate base, this portion of the project would not be subject to AFUDC charges and, therefore, would reduce the cost of the project.

HISTORY OF SECURITY RATINGS

Fixed Income Investment Grades

	Highest	High	Upper Medium	Medium	Lower Medium	Speculative	
Moody's	Aaa	Aa	A	Baa	Ba	B	1, 2, or 3 numerical notations where (1 highest)
Standard & Poors	AAA	AA	A	BBB	BB	B	
Duff & Phelps	1	2-4	5-7	8-10	11-13	14	

Common Stock Gradings

Value Line	TIMELINESS/SAFETY, numeric values 1-5, 1 highest, 2=ABOVE AVG., 3=AVG., 4 BELOW AVG., 5 Speculative.
Merrill Lynch	Suitability - A Investment Grade, B Good Quality, C Speculation, D High Risk OPR (short term/long term/income) 1 Buy, 2 OK to buy, 3 Neutral, 4 OK to Sell; 5 Sell, 6 No Opinion, 7 High Yield, 8 No Yield, 9 Low Yield

OHIO EDISON COMPANY

	FIRST MORTGAGE BONDS			POLLUTION CONTROL		PREFERRED STOCK (a)			PREFERENCE		COMMERCIAL PAPER		COMMON STOCK	
	Moody's	S & P	D & P	Moody's	S & P	Moody's	S & P	D & P	Moody's	S & P	Moody's	S & P	Value Line	Merrill Lynch
1969	Aa	AAA					AAA							
September, 1969	Aaa													
October, 1970		AA												
June, 1971							AA							
March, 1974						aa								
August, 1974	Aa													
January, 1975							A							
July, 1975		A					A-							
November, 1975						a								
April, 1976			7											
July, 1976	A					baa								
September, 1978		A-					BBB							
May, 1979													4/2	
August, 1979													3/2	
March, 1980		BBB+					BBB-							
June, 1980			8					9						
October, 1980													4/2	
July, 1981	Baa	BBB-			BB+	ba	BB			BB-				B-4-4-7
January, 1982														
February, 1982			9					10					2/2	
April, 1982	Baa3													

PENNSYLVANIA POWER COMPANY

	FIRST MORTGAGE BONDS			POLLUTION CONTROL		PREFERRED STOCK (a)			PREFERENCE		COMMERCIAL PAPER		COMMON STOCK	
	Moody's	S & P	D & P	Moody's	S & P	Moody's	S & P	D & P	Moody's	S & P	Moody's	S & P	Value Line	Merrill Lynch
February, 1972	Aa	AA												
May, 1972		A												
May, 1973				A	BBB									
October, 1973						a								
August, 1974	A			Baa										
March, 1975							A							
March, 1976							A-							
April, 1978	Baa			Ba		Baa								
September, 1980		BBB+			BBB-		BBB-							
April, 1982	Baa3		8					9						

(a) Moody's preferred stock rating service began in March, 1974.

OHIO EDISON FUEL CORPORATION

	COMMERCIAL PAPER Moody's	
April, 1982	P-1	(LOC-Manufacturers Hanover $ 67.5 mil (First Inter. of Calif 67.5 mil $135.0 mil

QUESTION:

9. WHERE DO YOU PURCHASE YOUR COAL AND WHAT IS ITS DELIVERED PRICE? WHAT IS THE METHOD AND COST OF TRANSPORTATION, IN DISTANCE HAULED?

ANSWER:

9. Coal purchased in Ohio, Pennsylvania, West Virginia and Kentucky. See attachments for delivered price and method of transportation. The cost of transportation is included in delivered price and cannot be broken out separately.

OHIO EDISON COAL QUANTITY AND COST DATA - 1980
(Currently Existing Plants)

PLANT Sammis 1-4

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	32.75	33631
	35.90	2911
	37.44	898
	35.96	115302
	36.63	4028
	36.94	53528
	36.24	277164
	35.27	5439
	38.44	157260
	41.35	425987
	41.23	39411
	38.31	231101
	41.19	96979
	42.86	399603
	32.33	1555
	38.61	(a)(6993
Total Truck	31.21	26638
Total Barge	39.73	1811164
Total Plant	39.61	1837802

PLANT Sammis 5-7

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	16.67	29247
	17.82	59632
	17.09	256972
	19.07	27782
	22.59	2194
	22.57	2793
	21.23	564
	23.51	2576
	24.50	3570
	27.00	1277
	28.41	49002
	30.40	29968
	30.84	76654
	32.17	403552
	31.42	117682
	31.88	96242
	31.55	75476
	32.06	138957
	32.93	165624
	32.57	204593
	35.06	150449
	37.08	1121105
	35.71	843
	36.57	8573
	40.76	2656
	38.41	486
	37.89	13952
	40.27	3598
	40.42	2730
	31.16	1295
	35.21	48
	38.61	(a)6993
Total Truck	29.29	1901799
Total Barge	37.39	1155286
Total Plant	32.45	3057085
		-
Total Plant	35.07	4894887

(a) Inter-supply transfer.

OHIO EDISON COAL QUANTITY AND COST DATA - 1980
(Currently Existing Plants)

PLANT Mad River

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	30.85	7933
	30.55	3483
	32.00	2979
	34.13	578
	36.37	13356
	35.00	313
	36.50	10817
	37.00	1247
	35.77	609
	39.51	8907
	37.68	14091
	39.25	924
	38.14	5497
	38.21	10947
	36.50	1043
	36.40	(a)(20)
Total Truck	33.85	30334
Total Barge	37.87	52370
Total Plant	36.40	82704

PLANT Gorge

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	19.90	9364
	19.70	7971
	21.64	33053
	23.05	7285
	23.05	10284
	23.65	16893
	25.53	24799
	25.28	22899
	26.94	28919
	26.70	126
	31.52	6611
	30.00	5578
	33.97	17044
	33.70	7564
	34.04	17417
	32.50	3555
	34.22	5065
	33.00	534
	33.30	2044
Total Truck	26.58	227005

(a) Bracket indicates ordered but not delivered.

OHIO EDISON COAL QUANTITY AND COST DATA - 1980
(Currently Existing Plants)

PLANT Niles

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	19.75	70026
	19.63	9480
	20.00	11230
	21.05	8779
	22.26	17293
	22.90	5165
	22.90	4836
	24.50	625
	30.00	36456
	30.17	29124
	31.58	76726
	31.22	59789
	34.68	13852
	33.76	31298
	33.21	10478
	35.19	114823
Total Truck	29.47	460378
Total Barge	31.03	39602
Total Plant	29.60	499980

PLANT Edgewater

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	17.09	1720
	24.89	1574
	27.28	12579
	28.25	4344
	30.00	38743
	30.50	34043
	31.60	58638
	31.24	3982
	34.97	20615
	34.75	1496
	38.65	21461
	39.48	112854
	43.60	25470
	41.65	33695
	42.08	30537
Total Truck	34.21	290588
Total Barge	42.63	111163
Total Plant	36.54	401751

PLANT R. E. Burger

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	27.35	12982
	31.73	14618
	32.70	45649
	30.59	43681
	32.59	14052
	45.01	929056
Total Truck	31.72	87301
Total Barge	44.36	972737
Total Plant	43.32	1060038

PLANT Toronto

PERIOD REPORTED Year 1980

	PRICE PER TON DEL. (14)	TONS RECEIVED (16)
	14.53	80854
	14.99	12866
	15.36	4628
	19.46	24935
	21.26	13353
	21.23	7400
	22.95	4477
	23.13	21177
	25.16	14078
	28.84	60567
	30.40	28934
	30.29	113383
	32.68	19826
	33.81	141
Total Truck	22.48	293236
Total Barge	30.31	113383
Total Plant	24.66	406619

QUESTION:

10. WHAT PERCENTAGE OF POLLUTION CONTROL EQUIPMENT HAVE YOU FINANCED WITH MUNICIPAL BONDS (POLLUTION REVENUE BONDS)?

ANSWER:

10. Including our most recent $50,000,000 of 11.75% Ohio Air Quality Development Authority issue placed in March of this year and backed by a Bankers Trust Company Letter of Credit, the Company has raised nearly $381,000,000 of tax preferenced funding. This source of funding presently represents slightly over 10% of the Company's corporate capital structure and as of year end 1981 the Company projects its existing aggregate environmental expenditure program for the period 1980-1986 at $605,000,000. The Company has and is continuing to fund, to the extent permitted, all qualifying expenditures with this form of tax-exempt financing. Practically speaking though, only about 75% of the "all in" costs meet this qualifying criteria.

QUESTION:

11. ABOUT HOW MANY POINTS BELOW THE MARKET IS THE INTEREST CHARGE.

ANSWER:

11. Our experience and current advice from major underwriting firms indicates that for the Company a 250 to 350 basis point spread would be anticipated on interest costs for conventional bonds versus employing pollution control tax exempt securities. Potential Treasury Department action and the large quantity of this type of financing being marketed over the past six months has significantly reduced the advantages to all affected parties which this form of financing had previously provided.

QUESTION:

12. IF THE 1971 NSPS REPLACED THE CURRENT STANDARDS FOR NEW POWER PLANTS, WHAT TYPE OF CONTROL METHOD WOULD YOU USE AND WHERE WOULD YOU BUY YOUR COAL? WHY?

ANSWER:

12. We plan no new coal-fired capacity at this time, and therefore, have not studied the question.

QUESTION:

13. WHAT ARE THE PROJECTED REVENUE REQUIREMENTS OF YOUR SYSTEM FOR EACH YEAR WITH S. 1706, VERSUS REVENUE REQUIREMENTS FOR THE SAME YEARS WITHOUT S. 1706?

ANSWER:

13. Based on projected aggregate capital expenditures of nearly $1.5 billion through 1987 and a current fixed charge rate (26.1%) on retrofit pollution control equipment, the rough estimate of the future additional revenue requirements associated with the capital aspect of S. 1706 would be $392 million annually. An additional annual revenue requirement for the operational aspect has been estimated at $105 million. In total the future additional annual requirements associated with implementation of the Mitchell Bill S. 1706 is a staggering $497 million which represents approximately 44% of the Company's 1981 operating revenue figure or potentially a 20% additional increase to a simplistically projected 1987 revenue figure.

QUESTION:

14. PLEASE PROVIDE GROWTH RATE ASSUMPTIONS TO YEARS 1990 AND 2000 AND YOUR CURRENT AND PROJECTED RESERVE MARGINS.

ANSWER:

14. Peak demand as forecasted by the Company is projected to grow at 1.89% between 1982 - 1990, and 2.09% between 1990 - 2000. Based on continuation of the Company's summer peak demand, reserve margins between now and 1995 are projected to range between 35% and 45%. During the slower than normal economy of 1981, the reserve margin experienced was approximately 41%.

QUESTION:

15. HOW MUCH AND FROM WHAT MARKETS DO YOU INTEND TO PURCHASE COAL UNDER A REDUCTION PROGRAM SIMILAR TO S. 1706?

ANSWER:

15. Under S. 1706, compliance fuel would be procured from eastern low sulfur suppliers.

QUESTION:

16. PROVIDE INFORMATION ON THE AGE, CAPACITY, SULPHUR AND NO_x EMISSION RATES, AND EXPECTED RETIREMENT DATES FOR EACH PLANT IN YOUR SYSTEM WITH AND WITHOUT A REDUCTION PROGRAM SIMILAR TO S. 1706. GIVEN CURRENT REPLACEMENT COSTS, PLEASE EXPLAIN ANY DIFFERENCES BETWEEN THE TWO DATES AS FULLY AS POSSIBLE.

ANSWER:
16.

PLANT	UNIT	AGE (Yrs.)	CAPACITY (MW)	Lb/MMBtu	
				SO_2	NO_x (Unknown for Ohio Plants)
Edgewater	2	55	5	3.14	-
	3	34	62	3.14	-
	4	25	104	3.14	-
Gorge	6	40	48	4.07	-
	7	34	48	4.07	-
Burger	1	39	66	9.02	-
	2	36	66	9.02	-
	3	33	100	9.02	-
	4	27	156	9.02	-
	5	27	156	9.02	-
Mad River	2	34	25	4.62	-
	3	34	24	4.62	-
Niles	1	30	115	5.7	-
	2	30	115	5.7	-
Mansfield	1	7	780	0.6	-
	2	5	780	0.6	-
	3	3	800	0.6	0.9
Toronto	5	39	42	8.1	-
	6	33	65	8.1	-
	7	33	65	8.1	-
Sammis	1	23	180	1.61	-
	2	22	180	1.61	-
	3	21	180	1.61	-
	4	20	180	1.61	-
	5	15	300	4.46	-
	6	13	650	4.46	-
	7	11	650	4.46	-
			5942	3.1 (weighted average)	

We do not have planned retirement dates for any of our plants and have not forecasted any retirement under S. 1706.

QUESTION:

17. (A) PLEASE PROVIDE A DETAILED BREAKDOWN OF SCRUBBER COSTS. INCLUDING WHETHER YOUR ESTIMATES INCLUDE SCRUBBER SPARES:

(B) PROVIDE INFORMATION ON THE REDUCTION PERCENTAGE, AGE AND REDUCTION IN OPERATING EFFICIENCIES FROM CURRENTLY- OPERATING SCRUBBERS IN YOUR SYSTEM.

ANSWER:

17. (A) See attached 1977 estimate for the W. H. Sammis Plant. This estimate shows typical design but was made prior to the retrofit of baghouses and precipitators at the plant. Costs shown would escalate considerably. See attachment.

(B) Scrubbers at Mansfield Plant can remove above 90% of the SO_2. These are new units (the oldest, 7 yrs.) and required a 5% derate in plant output due to increased electricity use within the plant and hence decreased electricity for delivery to our customers. Not only is the unit rating reduced but outages due to scrubber-related problems have reduced output by 10%.

COMMONWEALTH ASSOCIATES, INC.
PERFORMANCE/COST SUMMARY

PLANT W. H. Sammis Plant - Stratton, Ohio

COMPLIANCE STRATEGY CASE IIIa - Present Coal, Lime FGD On All Boilers (scrubbers)

UNIT OR STEAM GENERATOR (I.D. NO.)	1	2	3	4	5	6	7
RATING (MKW) - Demonstrated	188000	188000	193000	193000	330000	650000	650000
- Derate	9000	9000	9000	9000	18000	27000	26000
- Predicted	179000	179000	184000	184000	312000	623000	624000
AVAILABILITY PREDICTED	72 -	77 -	69 -	59 -	60 -	60 -	60 -
PRESENT COAL - % Sulfur	3.1	3.1	3.1	3.1	3.1	3.1	3.1
- % Ash	16.7	16.7	16.7	16.7	16.7	16.7	16.7
- BTU Content	10805	10805	10805	10805	10805	10805	10805
PROPOSED COAL - % Sulfur	3.0	3.0	3.0	3.0	3.0	3.0	3.0
- % Ash	15.5	15.5	15.5	15.5	15.5	15.5	15.5
- BTU Content	11200	11200	11200	11200	11200	11200	11200
HEAT RATE (BTU/NKWHR) - Existing	9690	9690	9440	9440	8950	9330	9330
- Predicted	10200	10200	9900	9900	9460	9740	9720
FIRING RATE (LBS/NKWHR) - Existing	0.897	0.897	0.874	0.874	0.828	0.864	0.864
- Predicted	0.909	0.909	0.884	0.884	0.845	0.869	0.868
PARTICULATE PRODUCED (TONS/HR) - Existing	11.968	11.968	11.968	11.968	19.391	39.846	39.846
- Predicted	10.717	10.717	10.717	10.717	17.363	35.679	35.679
COLLECTION RATE (TONS/HR) - Existing	10.771	10.173	10.173	9.574	18.421	37.854	37.854
- Predicted	10.626	10.626	10.626	10.626	17.233	35.375	35.375
ALLOWABLE EMISSION 0.1 LB/MM BTU							
EMISSION RATE (TONS/HR) - Existing	1.197	1.795	1.795	2.394	0.970	1.992	1.992
- Predicted	0.091	0.091	0.091	0.091	0.130	0.304	0.304
(LB/MM BTU) - Existing	1.314	1.971	1.971	2.627	0.657	0.657	0.657
- Predicted	0.10	0.10	0.10	0.10	0.088	0.10	0.10
SO_2 PRODUCED (TONS/HR) - Existing	5.228	5.228	5.228	5.228	8.470	17.404	17.404
- Predicted	4.88	4.88	4.88	4.88	7.907	15.748	15.748
REAGENT RATE (LBS/NKWHR) - Predicted	0.0321 TOTAL PLANT						
ABSORPTION RATE (LBS/NKWHR) - Predicted	0.033	0.033	0.033	0.033	0.031	0.033	0.033
ALLOWABLE EMISSION 2.91 LB/MM BTU							
EMISSION RATE (TONS/HR) - Existing	5.228	5.228	5.228	5.228	8.470	17.404	17.404
- Predicted	1.95	1.95	1.95	1.95	3.16	6.50	6.50
(LBS/MM BTU) - Existing	5.738	5.738	5.738	5.738	5.737	5.738	5.738
- Predicted	2.14	2.14	2.14	2.14	2.14	2.14	2.14
WASTE BY-PRODUCT RATE (TONS/HR) - Predicted	203 TOTAL PLANT						
DURATION OF FIELD ACTIVITY PER UNIT (MONTHS)	16	16	16	16	16	16	16
DURATION OF UNIT OUTAGE FOR CUTOVER (WEEKS)	6	6	6	6	6	6	6
CAPITAL COST ($ x 1000) - PARTICULATE	40450	40450	40450	40450	69342	99554	99554
- SO_2	28436	28436	28436	28436	48749	122308	122308
DOLLARS PER POUND OF POLLUTANT PER HOUR IMPROVEMENT - PARTICULATE	18300	11900	11900	8800	42200	29500	29500
- SO_2	4340	4340	4340	4340	4590	5600	5600
CURRENT BOOK VALUE OF EQUIPMENT WHICH WOULD BE RETIRED ($ x 1000)	66	73	92	103			

TOTAL CAPITAL COST	COST	CALENDAR OF IMPLEMENTATION
OPTIMUM FULL COMPLIANCE	$837,359,000	1977-1983

TABLE 5-4

QUESTION:

18. PLEASE INDICATE WHAT PERCENTAGE OF THE COAL BURNED BY YOUR SYSTEM IS WASHED AND WHY IT IS WASHED (ENVIRONMENT, CORROSION PREVENTION, ETC.). WHAT PERCENTAGE OF SULFUR IS REMOVED?

ANSWER:

18. Over half of the coal we burn is washed to remove ash and sulfur to achieve emission limits and to meet boiler design specifications. We have only one, small company-operated mine and have not developed data on percentage removal.

QUESTION:

19. HOW MUCH OF YOUR COAL COMES FROM MINES OUTSIDE THE S. 1706 ARMS REGION?

ANSWER:

19. None.

QUESTION:

20. PROVIDE YOUR ANALYSIS OF THE USE OF NO_x CONTROLS AS A PARTIAL OR COMPLETE ALTERNATIVE REDUCTION STRATEGY.

ANSWER:

20. It can be cost effective to substitute NO_x control for SO_2 control. However, high percentage reductions of NO_x emission cannot be achieved economically.

QUESTION:

22. PROVIDE ANY DOCUMENTATION ON RELIABILITY, OR EFFECTIVENESS AND COST OF NOX CONTROL DEVICES.

ANSWER:

22. We would like to direct your attention to the following Electric Power Research Institute publications:

A) EPRI CS-2075, December 1981, Preliminary Economic Analysis of No_x Flue Gas Treatment Process Using TVA and EPRI Economic Premises.

B) EPRI EA-2048, September 1981, Control of Nitrogen Oxides: Assessment of Needs and Options, Technical Support Document.

C) EPRI EA-2050, September 1981, NO_x Regulatory Changes and the Electric Utility.

D) EPRI FP-1109-SR, July 1979, Proceedings: Second NO_x Control Technology Seminar.

E) EPRI WS-79-220, May 1981, Proceedings of the Joint Symposium on Stationary Combustion NO_x Control.

QUESTION:

23. WOULD THE IMPOSITION OF MID-TERM EMISSIONS (E.G., 5 MILLION TONS AT 5 YEARS IF THE TOTAL GOAL IS 10 MILLION TONS IN 10 YEARS) REDUCTIONS INCREASE OR DECREASE LONG-TERM REDUCTION COSTS? WOULD IT ALTER YOUR CHOICE OF REDUCTION METHODS?

ANSWER:

23. Not determined.

QUESTION:

24. IF THE CONGRESS DECIDES THAT A 50 OR 75 PERCENT REDUCTION IN SO_2/NOx EMISSIONS IS A NECESSARY GOAL FOR THIS COUNTRY, WHAT IS YOUR VIEW OF THE MOST EFFICIENT MEANS OF ACHIEVING IT?

ANSWER:

24. Low sulfur fuels and combustion modification to reduce NOx.

QUESTION:

25. PLEASE STATE WHAT PERCENTAGE OF YOUR ELECTRICITY IS EITHER RECEIVED FROM OR SHIPPED TO OTHER UTILITIES. PLEASE ALSO STATE WHAT PERCENTAGE OF YOUR POWER IS GENERATED AT FACILITIES WHICH ARE OWNED OR OPERATED WITH OTHER UTILITIES.

ANSWER:

25. Purchased power represented 6.9% of power sold by Ohio Edison in 1980. Of our "capacity in-service" during 1981, 67.8% of it is capacity located in plants which are owned or operated with other utilities.

QUESTION:

MR. RUNYON:

1. PLEASE PROVIDE COST ESTIMATES (1980 DOLLARS) AND THEIR BASIS (REDUCTION STRATEGY RATIONALE). INCLUDE ESTIMATE OF REDUCTION LEVEL NEED AND RELEVANCE OF USING THE MANSFIELD PLANT.

ANSWER:

1. We agree that Mansfield capital costs may not be relevant. The costs are too low since significant escalation has occurred and the degree of difficulty associated with retrofits at our plants far surpasses anything contemplated in the Mansfield estimates. Working from the assumptions in the Commonwealth Associates, Inc. study and applying this over the company we estimate a capital expenditure of $1.5 billion. Using the Mansfield experience as a guide we calculate the operating and maintenance cost to run in the average of $120 million a year.

Union Electric Company
1901 GRATIOT STREET - ST. LOUIS

MAILING ADDRESS:
P.O. BOX 149
ST. LOUIS, MO. 63166

June 15, 1982

Mr. Curtis A. Moore
Associate Counsel
Senate Environment and
Public Works Committee Staff
Room 4204
Dirksen Senate Office Building
Washington, D.C. 20510

Dear Mr. Moore:

Please find enclosed answers to questions 1(B), 8, 13, 16, 17, 18, 21, and 23 relating to acid rain control costs, listed in your June 8, 1982 Mailgram. You were anxious to have answers to these questions at the earliest date. We will attempt to provide answers to the remaining questions as soon as possible.

All emission control costs submitted June 4, 1982 reflect the cost and revenue needed to bring the existing Union Electric generating system into compliance with S.1706 (10 million tons SO_2 emission reduction). New coal-fired capacity installed to serve future load must also have controls that will require a similar portion of new revenue. In addition, S.1706 would require offset for those new sources. Those offset costs were not accounted for in the analysis.

One might argue over whether environmental control costs should be assigned to acid rain control or to other factors, especially as old plants are retired and new plants built. However, regardless of how these costs are characterized, eventually a substantial part of the cost to produce a kilowatt of power from a coal-fired plant, 25% or so, will be due to emission controls imposed by federal law.

ANSWERS TO QUESTIONS

1(B). Information is available in material submitted June 4, 1982.

Sioux Plant - 215 $/Kw

Labadie Plant - 207.5 $/Kw

8(A). 1) At the present time no CWIP is allowed in the rate base under Missouri, Iowa, and Illinois jurisdictions.

2) Balances as of 12/31/81:

AFUDC = $160.2 million

Utility plant in-service = $2,671.9 million

Ratio $= \frac{160.2}{2,671.9} = 6\%$

3) Union Electric bond ratings through June 1982 are as follows:

Moody's	Baa - 1
Standard & Poor's	BBB
Duff & Phelps	8 (BBB+)

Specifically for pollution control bonds the ratings through June 1982 are:

Moody's	Baa - 1 (Secured by UE first mortgage bonds)
Standard & Poor's	BBB

8(B). We have not been able to develop a response to this question but will provide an answer as soon as possible.

13. Analysis based on a 1980 electric generating system.

Revenue required with S.1706 - $1,198,393,000

Revenue required without S.1706- $996,893,000

16.

Plant	Age*	Capacity Mw	Year 1980 Capacity Factor	Emission Limit lbs-SO_2 MM Btu	Tons SO_2 Emitted
Labadie	1970-73	2400(4-600 Mw)	62	4.8	237,000
Sioux	1967-68	1000(2-500 Mw)	49	4.8	97,200
RushIsland	1974-75	1200(2-600 Mw)	61	2.3	51,900
Meramec	1953-61	930 (2-140 Mw, 1-300 Mw, 1-350 Mw)	42	2.3	29,300

* Generally, we have considered the expected life of a power generating unit to be about 30 years. However, there has been a tendency to keep plants in service for a longer period of time, and because of increasing difficulty in permitting, financing, and construction, this trend is likely to continue.

NOx emission rates are not available for each plant. However, all but two of the pulverized coal-fired boilers (650 Mw) are tangentially fired and produce relatively low NOx emissions. Therefore, little potential exists for NOx controls. In addition, efforts to reduce NOx tend to increase hydrocarbon emissions and these plants are in an ozone nonattainment area. The boilers at Sioux Plant (2-500 Mw units) are cyclone fired and cannot be modified to significantly reduce NOx emissions.

17.(A) Scrubber Estimates	(Early 1983 Start-up) Labadie	(Late 1982 Start-up) Sioux
(Includes spare module on each unit) Absorber, tanks, pumps, fans, lime slaker, reaction tank, foundations, steel, breeching, site work, rail spur, disposal pond, building, lime handling, silos, dust collectors, piping electrical, instruments, and controls, etc.	$242,664,000	$106,689,000

17.(A) cont'd.

	Labadie	Sioux
Contingency	$ 43,678,000	$ 19,203,000
Escalation	129,084,000	54,700,000
Engineering	19,781,000	8,053,000
Land	1,500,000	-
Overhead	4,367,000	1,886,000
AFDC	52,747,000	22,686,000
Taxes	4,181,000	2,097,000
	$498,002,000	$215,314,000

17.(B) We have no operating scrubbers. However, the design of the systems upon which the costs listed under 17(A) were based assumed 90% removal efficiency of the gas treated. Only a portion of the gas was to be treated in this design to reduce emissions to 2.3 lbs-SO_2/mm Btu. Further reductions necessary under S.1706 would clearly require additional scrubber capacity at Labadie and may require additional capacity at Sioux.

NOTE:

1) Estimates were based on a start-of-construction date of July 1979, with start-up about the end of 1982.

2) Construction centroid was established as two-thirds through the project.

3) Escalation at 7% per year.

4) AFDC calculated at 7% compounded semiannually.

5) Fixed charge rates - Labadie 12.8%, Sioux 13.7%.

6) Demand charge 590$/Kw (1982 operation)

7) Costs do not reflect unit unavailability that will result from unavoidable outages of scrubber system.

18. About 75% of our coal is washed mainly to improve boiler operation. About 20% of the sulfur is removed.

21. Same question as 8(B).

23. As indicated in our submission at the June 4, 1982 hearing, scrubber costs used in the Union Electric presentation reflect fixed charge rates and other costs that are clearly lower than present day costs. The fixed charge rate used for Labadie was 12.8%, and 13.7% for Sioux. Fixed charge rate that we would apply to new construction would be about 16.5%.

In response to questions, I indicated that a current detailed analysis of scrubber costs would likely swing our choice of compliance options to the use of low sulfur coal. Therefore, our short-term or long-term choice would likely be low sulfur coal, and my best guess as to compliance costs for a 5 million ton reduction would be $100 million to $115 million annually, which would represent an approximate 10% increase in revenue needs.

I hope you will find this information useful. We will send you answers to the remaining questions as soon as we can develop the information.

Sincerely,

Jerrel D. Smith

Jerrel D. Smith
Manager
Environmental Services

JDS/dg

UNION ELECTRIC COMPANY
1901 GRATIOT STREET - ST. LOUIS

MAILING ADDRESS:
P. O. BOX 149
ST. LOUIS, MO. 63166

June 28, 1982

Mr. Curtis A. Moore
Associate Counsel
Senate Environment &
Public Works Committee Staff
Room 4204
Dirksen Senate Office Building
Washington, D.C. 20510

Dear Mr. Moore:

Following are our remaining answers to questions on acid rain control costs contained in your June 8, 1982 Mailgram.

1. See our June 15, 1982 response.

2. As previously indicated, SO_2 emission control costs associated with power generated from coal-fired plants will continue to be a significant percentage (20% to 25%) of electric revenue required to support that production, regardless of whether those costs are characterized as acid rain control costs or assigned to other reasons.

3. There are no further planned SO_2 emission reductions. Total system SO_2 emissions are not expected to change significantly by 1990.

4. A) Approximately 25% to 35%.

   B) Approximately 35% to 45%.

   C) As previously stated, although our analysis was based on the application of scrubbers and low sulfur coal, the most likely option to be selected would be low sulfur coal, once a more current and thorough analysis of scrubber costs was completed. Therefore, there would be little change in capital costs or $/ton removed on the system. The annual cost on the U.E. system under a five million ton per year reduction plan would be about 100 to 115 million dollars, or a 10% increase in revenue. This would represent a cost of about 720$/ton to 825$/ton of sulfur dioxide removed.

5. Although we cannot specifically quantify the savings to the customer that might result from providing certain flexibility suggested in question number 5, clearly any action designed to reduce regulatory lag, include CWIP in the rate base, and allow automatic fuel adjustment, would reduce the overall cost of controls. These actions would produce only modest savings compared to the overall cost of controls, but would, nonetheless, be useful. The cost of control equipment would be a significant financing burden. Therefore, the ability to receive prompt rate relief on pollution control equipment would tend to protect against lower financial ratings that would drive up the cost of such systems.

6. CARRYING CHARGES ON CAPITAL INVESTMENT

* Short lead time additions to coal-fired plants
* Post 1985 ACRS tax depreciation
* Conventional financing

Cost of Capital		13.66%
Depreciation (30 year sinking fund)		0.48
Income Taxes		
Normal	2.21%	
Less Investment Tax Credit	-2.14	
Net		0.02
Property Tax		2.00
Total		16.16%

Carrying charges for earlier installation:

Pre-1985 ACRS	17.04%
1985 ACRS	16.22

For planning purposes, Union Electric assumes that tax exempt pollution control bonds and notes will not be allowed by law beyond 1982.

At the present time, investment bankers have advised Union Electric that because of the Baa-1 bond rating, there is no assurance that UE can sell long-term pollution control bonds. Instead, the investment bankers advise, UE can only reasonably expect to sell short-term (1-5 year term) tax exempt pollution control notes.

7. The fixed charge rates used in the UE estimates were 12.8% for one plant, and 13.7% for a second plant.

The CURRENT WEIGHTED COST OF CAPITAL is as follows:

46% Long-term Debt at 11% = 5.06%
14% Preferred Equity at 10% = 1.40
40% Common Equity at 18% = 7.20

Weighted Cost of Capital 13.66%

Discount Rate

After-tax Cost of Money
47.66% Composite Income Tax Rate

13.66 - (0.4766 x 5.06) = 11.25%

Recently Allowed Return on Equity is:

FERC	13.0%	(Sept. 1980)
Missouri	14.6%	(July 1981, imputed)(New order due 7/82)
Illinois	15.3%	(April 1981)
Iowa	14.5%	(Sept. 1981, stipulated)

8.(A) Q. What portion of CWIP, if any, are you allowed to place in your rate base?

A. At the present time, no CWIP is allowed in the rate base under Missouri, Iowa, and Illinois jurisdictions.

Q. What portion of current assets are AFUDC?

A. Balances as of 12/31/81:

AFUDC = $160.2 million

Utility plant in-service = $2,671.9 million

$$\text{Ratio} = \frac{160.2}{2,671.9} = 6\%$$

Q. What is your present bond rating?

A. Union Electric bond ratings through June 1982 are as follows:

Moody's	Baa-1
Standard & Poor's	BBB
Duff & Phelps	8 (BBB+)

Specifically for pollution control bonds, the ratings through June 1982 are:

Moody's	Baa-1 (Secured by UE first mortgage bonds)
Standard & Poor's	BBB

8.(B) Consider as an example of pollution control equipment the scrubber estimates in item 17.(A). If CWIP would have been allowed in the rate base from the beginning of the project, the electric customer would have been paying the financing costs associated with this project during the period of construction and no AFDC amounts would have been capitalized. The result of this lower capitalization would be a lower required return due to (i) a smaller rate base (approximately 10% in this case), and (ii) reduced cost of capital since the customer paying the financing costs would have relieved the need for additional security sales.

Also, reduced capitalization would be reflected in lower property taxes as well as lower depreciation. Although total capitalized costs for this scrubber equipment would be reduced, the customers would experience higher rates during the construction period as a result of paying for the financing costs of the project during the construction period. However, these financing costs would be more than offset by the project's lower fixed costs during its operating life.

Savings would accrue to the ratepayer if CWIP would be included in the rate base. Due to such things as improved interest coverage under the bond indenture, better quality earnings, and improved cash flow, savings would result from improved financial security ratings. Although the differential cost of bonds varies, at times the spread between A and Baa bond ratings has reached 100 basis points (one percent per annum).

9. Most of our coal is presently coming from Illinois. The price per ton for the system is currently about $30.00/ton. All of the coal is transported by unit trains except for the Meramec Plant which receives coal by barge. Transportation charges vary from $2.80/ton to $6.04/ton. Distances hauled vary from 120 miles to almost 200 miles.

10. Since the State Environmental Improvement Authority of the State of Missouri was created in 1973, Union Electric has financed all qualified pollution control expenditures allowed by law with pollution control bonds and notes. About 1/3 of our environmental capital expenditures are financed with pollution control bonds and notes.

Operating expenses associated with environmental control activities for the next five years are expected to be about $430 million, much of which is the cost for cleaner fuels.

11.A) Currently, 30 year pollution control bonds, if they could be sold at all, are expected to be only 2 percentage points below our 30 yr. 1st mtg bond rate. Short-term pollution control notes (1-5 yr. term) are expected to be 5 percentage points below the 30 yr. 1st mtg bond rate. For reasons stated in the answer to question #6, UE would expect to refinance these short term tax exempt notes with taxable bonds at maturity at the higher, taxable rate.

B) UE intends to finance all future qualified pollution control expenditures with pollution control bonds and notes as allowed by law.

A new form of tax exempt pollution control bond is being considered by UE called a put bond.

12. If the 1971 NSPS replaced the current standard, an economic analysis of the cost of low sulfur western coal and scrubbers would be made to see which control option should be selected. On a new source this might be a close call. However, restoring this important competitive element to the decision-making process would result in lower overall control cost to the customers.

13. See our June 15, 1982 response.

14. GROWTH RATES

From 1981-1990	From 1990-2000
Demand - 2.0%	Demand 2.5%
Energy - 2.9%	Energy 3.9%

PROJECTED RESERVE MARGINS

	1982	1990	2000
Reserves (Mw)	1198	1318	1946
Demand Requirements (Mw)	6090	7150	9420
Percentage	19.7%	18.4%	20.6%

15. It is not possible at this time to clearly determine the source of low sulfur coal that might be used to implement an emission reduction plan. However, competition in the eastern coal markets would probably make the cost of western low sulfur coal attractive.

16., 17., 18.) See our June 15, 1982 response.

19. 500,000 tons per year out of a total of 12 million tons.

20. As previously stated, because most boilers in the system are relatively low emitters of NOx or cannot be economically modified because of the design features, there is little hope of obtaining significant reduction of NOx.

21. See our June 15, 1982 response.

22. No information available.

23. See our June 15, 1982 response.

24. Any SO_2 emission reductions on the UE system must be achieved through the use of low sulfur coal or the application of scrubbers. The most economic option would have to be determined to conform with any state plan devised to achieve a specified reduction.

25. Following is a tabulation of interchange and shared capacity.

FOR YEAR 1981

	MWh	%
Net Native Load	25,956,505.1	100.0
Actual Interchange		
Purchases	8,928,317.0	34.4
Sales	8,330,502.0	32.1

FOR YEAR 1981

	MW	MWh
Electric Energy, Inc.(EEI)	350	1,271,742.5
Operable Resources	7158	
Net Native Load		25,956,505.1
EEI Percentage	4.9%	4.9%

SPECIFIC QUESTIONS - (Mr. Smith)

The cost analysis presented on June 4, 1982 was based on the use of low sulfur coal at two plants and scrubbers at two plants. The rationale was provided on pages 4 & 5 of that submission, which is attached. (Attachment 1)

The type of fuel used at the Rush Island and Meramec plants is coal, most of which comes from Illinois.

I hope you will find this information useful.

Sincerely,

Jerrel Smith

Jerrel D. Smith
Manager
Environmental Services

JDS/dg

Attachment 1.

D. Selected plan for estimating cost of compliance with S.1706.

1. A detailed engineering study for scrubber installation at Sioux and Labadie was completed in late 1978 (prepared by Gilbert Commonwealth Associates of Jackson, Michigan). Costs were based on start of construction 7/1/79, with start-up mid-1983.

2. Fixed charge rate has increased approximately 30% since these studies were completed. About 75% of total annual cost is the cost of ownership. Therefore, total annual cost as shown should be increased 20% to 25% to reflect current financing conditions.

3. Labadie: Scrubbers would be the lowest cost emission reduction alternative based on the data shown. This could quickly change if the cost of the present medium sulfur midwestern coal was to increase significantly on the system. It is very questionable whether compliance with particulate emission limitations could be achieved while burning a 1.4 lb-SO_2/mm Btu coal, even after completion of the ongoing project of upgrading precipitators. Therefore, the scrubber option is selected for this cost analysis.

Sioux: The annual cost to own and operate scrubbers is about equal to the cost of low sulfur coal based on the data presented. After adjusting the cost of scrubber ownership to reflect a more representative fixed charge rate, scrubbers would appear to be more costly than low sulfur coal. However, experience has shown that burning high percentages (50% or greater) low sulfur coal can result in serious load limitations on the plant. In addition, precipitators at Sioux would not meet particulate emission limits while burning low sulfur coal. These factors support the scrubbers option at Sioux as the emission control choice for this analysis.

Rush Island: The cost of the low sulfur coal option appears to be about equal to the scrubber option at Rush Island. This is the newest plant and has precipitators that would probably comply with particulate emission limits while burning low sulfur coal. Therefore, the low sulfur coal option was selected for purposes of this analysis.

Meramec: Meramec is the oldest of the four plants. Its capacity factor is the lowest of the coal-burning plants and will probably decline somewhat in future years. Precipitator additions, completed on this plant in 1981 at a cost of $55/Kw, should achieve compliance with particulate emission limits while burning a lower percent sulfur coal. The low sulfur coal option is clearly the best choice for SO_2 emission reductions.

New England Power Service

New England Power Service Company
20 Turnpike Road
Westborough, Massachusetts 01581
Tel. (617) 366-9011

John F. Kaslow
Vice President

June 10, 1982

Mr. Curtis A. Moore
Senate Environment and Public Works Committee
Rm 4204
Dirksen Senate Office Building
Washington, D.C. 20510

Dear Mr. Moore:

Enclosed you will find our response to the questions in your June 8, 1982 Mailgram. Unlike most of the utilities represented at the recent Committee staff meeting whose SO_2 emission reduction plans would affect coal burning units, the Mitchell Bill impact on our New England Electric generating units would affect oil burning units. As a result, some of the questions on the list are not particularly relevant to our situation.

Should you or your staff associates desire further information, please do not hesitate to contact me.

Yours very truly,

John F. Kaslow

A New England Electric System company

NEW ENGLAND ELECTRIC
Response to June 8, 1982 Questions

1. (A) No scrubbers were involved in our analysis. Residual oil sulfur content would be gradually reduced over the 10 year period - starting with our current 2.2% sulfur level and declining to 0.3% sulfur in the 10th year. The following is our projection of the per barrel differential costs of the various sulfur content oils in 1982 dollars. (The differentials indicated below would probably show little difference from 1980 to 1982. Over a short time span the differentials are less sensitive to inflation than to supply/demand.)

Base	2.2% sulfur oil	Base
	* 1.0%	Base + $4/barrel
	0.5%	Base + $6.50/barrel
	0.3%	Base + $7.75/barrel

* Our system has, in recent years, bought both 2.2 and 1.0% sulfur oils. The differential has varied from $3 to 5/bbl. We have not used 0.5 and 0.3% sulfur oils and have estimated these differentials.

1. (B) - Not applicable

2. We did not carry out our analysis beyond 1995. However, with no significant change in our generating mix anticipated before the year 2000, the gradual, continuing reduction in oil sulfur content to offset load growth will, in my view, result in incremental percentage increases in the projected electricity rates.

3. We expect an interim reduction in SO_2 emissions as planned nuclear units come on line - followed by SO_2 levels reaching current levels and eventually exceeding current levels as load growth continues. We are currently operating below SIP limits and have factored these points into our analysis. No unit retirements are planned during the period.

4. The estimated cost to NEES in the period 1983/1995 of the present Mitchell Bill is $351 million in 1981 dollars. A change in the Bill requiring 80% of the present rollback provision would reduce the cost to NEES to $300 million.

5. Since our SO_2 emission reductions would be accomplished by using lower sulfur oil on two large units, recovery of higher fuel costs via fuel adjustment clauses will be a necessity. The only other form of SO_2 reduction currently possible is scrubbing and there just is not adequate space available to scrub on these units. For units for which scrubbing is feasible, some form of reducing financing costs and accelerated capital recovery would appear to be in order.

6. Not pertinent since no major capital investment is required.

7. Not applicable since no major capital investment is required.

8. (A) & (B) - Not applicable (see above)

9. Not applicable - SO_2 reductions accomplished via oil sulfur reduction.

10. Percentage has varied over time - in one recent major pollution control project, 100% of the pollution control cost was financed via pollution control bonds.

11. The difference between market interest rates and pollution control financing interest rates is subject to fluctuation. Currently, the differential is approximately three percentage points.

12. No new generating capacity planned until beyond the year 2000. While the answer is not clear - based on our lack of experience in building new coal fired plants - certainly the options would be enhanced.

13. The difference in System revenue requirements with and without the Mitchell Bill is due entirely to increased fuel cost with the Bill. This increased fuel cost is $351 million for the period 1983-1995 (in 1981 dollars)

14. System peak load growth from 1980 to 1990 and 1980 to 2000 is currently forecast to be 1.3% and 1.4%, respectively, on a compound annual basis. The growth rates for energy demand are forecast to be 1.4% from 1980 to 1990 and 1.5% from 1980 to 2000.

    Expected capacity reserve margins, assuming no capacity additions beyond present commitments, are 39% in 1990 and 23% in 2000.

15. Not applicable

16. The System generating units impacted by the Mitchell Bill are Brayton Point 4 and Salem Harbor 4. The requested data is listed below:

Unit	Age (yrs)	Present Capacity Rating (MW)	Year of Emission Rate	Emission Rates (#SO_2/MMBTU) W/O Reduction Program		Emission Rate (#SO_2/MMBTU) W/ Reduction Program	
				SO_2	NO_x	SO_2	NO_x
Brayton 4	8	447	1990	2.42	Note	1.10	Note
			1995	2.42	1	0.34	1
Salem 4	10	444	1990	2.42	Note	1.10	Note
			1995	2.42	2	0.34	2

Estimated retirement dates are 2004 and 2002 respectively.

Note 1 The Massachusetts State limit for Brayton 4 is 0.3 #NO_x/MMBTU. This limit would have to be met with or without the Mitchell Bill. NO_x emissions are controlled by plant operation.

Note 2 There is no NO_x regulatory limit for Salem 4. Actual emissions are not routinely measured. Due to the many factors which affect NO_x emissions (nitrogen in fuel, plant operating factors, etc.), it is not possible to predict whether NO_x emission rates would increase or decrease with the Mitchell Bill.

17. (A) & (B) - Not applicable

18. Our System coal purchases consist entirely of washed coal. This washing process removes ash as well as pyritic sulfur content of the coal. The washing process lowers the coal's sulfur content from 1.5% to approximately 1.2% for a sulfur reduction of about 20% by weight.

19. All of the coal burned in our coal burning units comes from within the ARMS region.

20. We have little experience with NO_x controls, only sparse data on NO_x emissions from our units and do not have sufficient experience to comment on this question.

21. Since no major capital investment is envisioned, the CWIP question is not particularly relevant to our analysis.

22. We have no relevant experience in this area.

23. It would have little impact on our likely emission reduction strategy since oil sulfur content reductions can be achieved in an incremental fashion - at significant incremental cost.

24. The impacts of emissions reduction proposals are so diverse and regional, company and site specific, that the answer is exceedingly difficult. If emissions reduction for SO_2/NO_x were mandated, it would appear that:

    a) there should be a phase-in period

    b) the reduction target should be technologically and economically feasible

    c) all sources should carry a proportionate burden (i.e., all mobile and stationary sources) within the constraints of b)

d) equity be considered in terms of the current level of emissions within and between groups of sources in the stationary and mobile categories

e) flexibility be permitted in achieving the required emissions reductions

Notwithstanding these points, the more fundamental issue is what benefit is achieved for the national costs involved. It appears that benefits to be derived from an emissions reduction program are far more speculative than the costs of the reduction program.

25. Based on 1981 total System electric energy generation, 7.5% of the energy was transmitted to other utilities and 25.6% was received from other utilities. These purchases and receipts are composed of long and short term contracts, joint ownership generation and pool interchange. The percentage of this total System generation which is produced by generating units owned or operated with other utilities is 14.1%

NEW YORK POWER POOL
3890 Carman Road
Schenectady, New York 12303

June 16, 1982

VIA ELECTRONIC MAIL & HAND-DELIVERED

Mr. Curtis Moore
Associate Committee Counsel
Senate Committee on Environmental
and Public Works
Dirkson Office Building, Room 4206
Washington, DC

Dear Mr. Moore:

Enclosed are responses to various questions that you posed to me in your mailgram, dated June 8, 1982. Due to time constraints, the information may not be as complete as the staff may have desired, but it is indicative of the projected impacts of S.1706 on New York's electricity consumers.

Sincerely,

Kurt D. Anderson By CObt

Kurt D. Anderson
Environmental Affairs Manager

KDA:dv
Enc.

Question 1 (B).

Regarding scrubber capital costs, please provide estimates of dollars-per-kilowatt for each unit to be retrofitted.

Answer 1 (B).

The New York electric utilities that presently operate coal-fired plants have not made conceptual or detailed engineering studies of how these plants would be retrofitted with scrubbers; therefore, we can only estimate the costs for such retrofits. These estimates are included in the two-page document entitled, "Cost Impact of Senate 1706, Senator Mitchell, et al, on the New York Electric Utilities," that I left with the Committee Staff on June 3, 1982.

Question 8 (A).

What portion of CWIP, if any, are you allowed to place in your rate base? What portion of current assets are AFDUC? What is your present bond-rating?

Answer 8 (A).

The member systems of the New York Power Pool are eight electric utilities, which include seven investor-owned utilities and the State-owned Power Authority. The seven investor-owned system rates are regulated by the New York State Public Service Commission, which has permitted different amounts of CWIP in the rate base for different utilities. The amount of CWIP permitted varies from approximately 40 percent to zero, depending on the utility. Due to different ratemaking treatment of funds used during construction, the ratio AFDUC to current assets ranges from about 30 percent, down to a minor amount. The bond ratings vary by member systems as well.

Question 8 (B).

What would be the impact on projected reduction costs of allowing CWIP for pollution control equipment into your current rate base?

Answer 8 (B).

The allowance of CWIP in the rate base for pollution control equipment will not have a major impact on the aggregated cost of electric power in New York State.

Question 13.

What are the projected revenue requirements of your system for each year with S.1706, versus revenue requirements for the same years without S.1706?

Answer 13.

Only New York State Electric and Gas Corporation has projected the revenue requirements, as noted below:

New York State Electric & Gas Corp.	1982	1983	2000
Without S.1706 ($ X 10^6)	609	943	Approx. $100 million/yr. above requirement without S.1706
With S.1706 ($ X 10^6)	705	1039	

Question 16.
Provide information on the age, capacity, sulfur and NO_x emission rates, and expected retirement dates for each plant in your system with and without a reduction program similar to S.1706. Given current replacement costs, please explain any differences between the two dates as fully as possible.

Answer 16.

Unit	Age (Years)	Capacity (MW)	SO_2 Emission Rate (#/MMBTU)	NO_x Emission Rate (#/MMBTU)	Ret. Date (Year)

Note: Con Edison units burn 0.3% sulfur oil, SO_2 emissions rates are approximately 0.33#/10^6 BTU and NO_x emission rates are 0.24#/10^6 BTU.

Unit	Age (Years)	SO_2 Emission Capacity (MW)	NO_x Emission Rate (#/MMBTU)	Rate (#/MMBTU)	Ret. Date (Year)
OWNER: Long Island Lighting Company					
Glenwood #4		99	1.1	0.3	Not Planned
Glenwood #5		99	1.1	0.3	" "
Barrett #1		175	1.7	0.3	" "
Barrett #2		175	1.7	0.3	" "
Port Jefferson #1		42	1.1	0.3	" "
Port Jefferson #2		42	1.1	0.3	" "
Port Jefferson #3		175	3.06	0.3	" "
Port Jefferson #4		175	3.06	0.3	" "
Northport #1		358	3.06	0.3	" "
Northport #2		358	3.06	0.3	" "
Northport #3		357	3.06	0.3	" "
Northport #4		357	0.8	0.3	" "
OWNER: New York State Electric and Gas Corporation					
Goudey #7	39	44	3.4	0.78	Not planned
Goudey #8	30	85	3.4	0.78	" "
Greenidge #1	44	23	3.6	0.72	" "
Greenidge #2	40	20	3.6	0.72	" "
Greendige #3	32	54	3.6	0.72	" "
Greendige #4	29	106	3.6	0.72	" "
Jennison #1	37	35	1.7	0.60	" "
Jennison #2	32	40	1.7	0.60	" "
Hickling #1	34	37	1.5	0.53	" "
Hickling #2	30	50	1.5	0.53	" "
Milliken #1	27	158	3.2	0.77	" "
Milliken #2	24	147	3.2	0.77	" "
OWNER: Niagara Mohawk Power Corporation					
Dunkirk #1	30	85	3.58	0.75	Not planned
Dunkirk #2	30	85	3.58	0.75	" "
Dunkirk #3	22	185	3.58	0.75	" "
Dunkirk #4	20	185	3.58	0.75	" "
Huntley #63		80	2.30	0.86	" "
Huntley #64		85	2.30	0.86	" "
Huntley #65		85	2.30	0.86	" "
Huntley #66		85	2.30	0.86	" "
Huntley #67		185	2.30	0.86	" "
Huntley #68		185	2.30	0.86	" "
Albany #1		100	2.16	0.34	" "
Albany #4		100	2.16	0.34	" "

Unit	Age (Years)	Capacity (MW)	SO_2 Emission Rate (#/MMBTU)	NO_x Emission Rate (#/MMBTU)	Ret. Date (Year)
Oswego #1		70	1.1	0.62	Not Planned
Oswego #2		0	1.1	0.62	" "
Oswego #3		85	1.1	0.62	" "
Oswego #4		90	1.1	0.62	" "
Oswego #5		850	3.02	0.3	" "
Oswego #6		646	.81	0.3	" "
OWNER: Orange and Rockland Utilities, Inc.					
Bowline Pt. #1	10	600	0.63	0.29	Not Planned
Bowline Pt. #2	8	600	0.63	0.29	" "
Lovett #1	33	20	0.39	0.72	" "
Lovett #2	31	20	0.39	0.72	" "
Lovett #3	27	66	0.39	0.72	" "
Lovett #4	16	197.5	0.39	0.72	" "
Lovett #5	13	202	0.39	0.72	" "

The member systems of the New York Power Pool have not determined if the enactment of a bill such as S.1706 would affect the retirement dates of their units.

Question 17 (A).
Please provide a detailed breakdown of scrubber costs, including whether your estimates include scrubber spares.

Question 17 (B).
Provide information on the reduction percentage, age and reduction in operating efficiencies from currently-operating scrubbers in your system.

Answer 17 (A) and (B).
Since New York utilities do not presently operate any scrubbers, the costs associated with them can only be estimated. The estimates are contained in the answer to Question 1 (B).

Question 18.
Please indicate what percentage of the coal burned by your system is portion of their coal. The percentages washed and the reasons are as follows:

New York State Electric & Gas Corp. - 40% washed to be marketable 20% sulfur removed

Niagara Mohawk Power Corporation - 61% washed in 1981 to reduce ash content

Rochester Gas & Electric Corp. - 25% washed for ash removal

Question 21.

What would be the impact on projected reduction costs of allowing CWIP for pollution control equipment into your current rate base?

Answer 21.

See answer to Question 8 (B).

Question 23.

Would the imposition of mid-term emissions (e.g., 5 million tons at 5 years if the total goal is 10 million tons in 10 years) reductions increase or decrease long-term reduction costs? Would it alter your choice of reduction methods?

Answer 23.

A phased emission reduction program would cause increased costs and alter the choice of reduction methods.

Specific Witness Question.

Please provide current and projected SO_2 and NO_x emission rates for the 15 units to be converted to coal (before and after conversion). How many additional tons per year will each of these conversions add up to?

Specific Witness Answer.

Unit	Prior to Conversion SO_2 (#/MMBTU)	NO_x	Increased SO_2 Tons/Yr.	Increased NO_x Tons/Yr.
OWNER: Central Hudson Gas & Electric Corporation				
Danskammer	1.1	0.43		
After Conversion				
Danskammer	2.4	0.72	4,133	5,661
OWNER: Consolidated Edison Co. of NY, Inc.				
Prior to Conversion				
Ravenswood #3	1.55	0.25		
Arthur Kill #2, #3	1.55	0.25		
After Conversion				
Ravenswood #3	1.51	0.70	35,510	15,040
Arthur Kill #2, #3	1.51	0.70	31,300	13,000
OWNER: Long Island Lighting Company				
Prior to Conversion SO_2 (#/MMBTU)				
Port Jefferson #3, #4	3.06	0.3		
Barrett #1, #2	1.7	0.3		
After Conversion				
Port Jefferson #3, #4	2.93	0.69		
Barrett #1, #2	1.52	0.69	No increase	

There would be no increase in actual system emissions with either conversion since the maximum emission rates are the same and the capacity factors would be either comparable to the present or offset by reductions in capacity factors of oil-fired units with comparable emission rates. The increase in NO_x emission rates of approximately 1900 tons/yr. for Port Jefferson and for Barrett, based on a capacity factor of 0.75 and an emission rate of 0.6 lb/10^6 BTU. It should be noted, however, that while both plants are currently in the SEO and NYPP plans, permit applications have been filed only for Port Jefferson. With present economics, it is likely that if Port Jefferson is converted, Barrett will not be.

Unit	Prior to Conversion SO_2 (#/MMBTU)	NO_x	Increased SO_2 (#/MMBTU) Tons/Yr.	Increased NO_x Tons/Yr.
OWNER: New York State Electric and Gas Corporation - NA				
OWNER: Niagara Mohawk Power Corporation				
Prior to Conversion				
Albany	2.16	0.34		
After Conversion				
Albany	2.16	0.75	None	4,470
OWNER: Orange and Rockland Utilities, Inc.				
Lovett #4	0.39	0.72		
Lovett #5	0.39	0.72		
After Conversion				

Tennessee Valley Authority's Responses to Questions Asked During June 9 Briefing On Acid Rain Compliance Issues

This constitutes the Tennessee Valley Authority's (TVA) initial responses to the written and verbal questions asked during the June 9 briefing of staff of the Senate Committee on the Environment and Public Works on acid rain compliance issues. The numbered responses correspond to the numbers of the written questions submitted to TVA. The letter responses correspond to the verbal questions asked at the June 9 briefing. Because of time constraints, not every question has been responded to. Responses to any unanswered questions will be provided as soon as possible.

1. (a) If your estimate of scrubber costs varied by more than 50 percent from the estimates in the CBO appendix, please explain why. If your estimated costs for cleaner fuels vary by more than 30 percent, again explain. Also, please provide historical fuel prices (by SO_2 emission rate) paid by your utility.

(b) Regarding scrubber capital costs, please provide estimates of dollars-per-kilowatt for each unit to be retrofitted.

Answer: (a.) Not applicable

(b.) TVA's cost estimates were based on the assumption that scrubbers could be retrofitted on its existing units for $155/kW (1982 dollars). This is based on our experience with scrubber retrofits plus a contingency for unknown interface problems. Site specific estimates of the cost of retrofitting scrubbers have not been made and could vary significantly between plants depending on the actual retrofit complications.

2. When calculating percentage increases in electricity rates due to an acid rain control program, do these percentages remain constant past 1990 (e.g., 2000, 2010)?

Answer: It is unlikely that the percentage increase in electricity rates due to an acid rain control program proposed under S. 1706 would remain constant after 1990. If new coal-fired capacity is added to supply loads after 1990, the percentage increase would tend to go up. If new loads are supplied from a source that does not emit SO_2 (nuclear for example) the percentage would tend to go down.

3. If no additional regulations are imposed will your utility be reducing emissions from current actual levels anyway (e.g., to meet SIP compliance, retirement, etc.)? Were the costs of these reductions included in your cost estimates?

Answer: SO_2 emissions will be reduced significantly from 1980 emissions in accordance with current plans and expectations. TVA's 1980 emissions were approximately 1.6 million tons. After 1983 emissions will drop to about 1.1 million tons per year as our coal-fired plants come into final compliance with existing requirements. Annual emissions are expected to drop an additional 0.1 million tons during the 1980's due to decreased use of the coal-fired plants when additional nuclear units come on line. Resulting emissions would be on the order of 1.0 million tons per year depending on the actual coal burn. Emissions in the 1990's are expected to be between 0.85 and 1.3 million tons per year based on TVA's low- and high-load forecasts for that period. The costs of the reductions in emissions brought about by coming into compliance with existing emission requirements are not included in the costs for compliance with the acid rain reduction program.

4. (a) If the emission reductions required by an acid rain control program were 80 percent of the tonnage assumed in your calculations, by how much would your costs be reduced (provide your best estimate, e.g., 10-percent, 25-percent, 50-percent reduction in cost)?

(b) If the emission reductions were 60 percent of the tonnage assumed?

(c) All other things being equal, if S. 1706 as now drafted required a 5 million ton SO_2 reduction from current levels rather than 10 million tons, how would it affect key factors such as:

--total capital costs

--$/ton removed

--electricity rates

--annual costs.

Answer: Later

5. If you were required to reduce emissions under S. 1706, in what three ways (in order of priority) might utility costs of the control program be reduced (e.g., automatic fuel price adjustment clauses) and in what three ways might consumer costs be reduced?

Answer: Not applicable - all of TVA's costs are borne by its consumer.

6. Please explain your choice of the components of carrying charges on capital investment. What do you assume as to the availability of pollution control bonds?

Answer: In calculating the costs of additional pollution controls, TVA used a cost of capital rate of 12 percent. This rate is consistent with the rate TVA used in its evaluation of other types of proposed projects. The second part of the question is not applicable to TVA.

7. What is the weighted cost of capital used in your assumptions? Is that the same rate allowed by your public utility commission in rate setting?

Answer: See answer to question 6.

8. (a) What portion of CWIP, if any, are you allowed to place in your rate base? What portion of current assets are AFDUC? What is your present bond rating?

(b) What would be the impact on projected reduction costs of allowing CWIP for pollution control equipment into your current rate base?

Answer: Not applicable.

9. Where do you purchase your coal and what is its delivered price? What is the method and cost of transportation, in distance hauled?

Answer: Later

10. What percentage of pollution control equipment have you financed with municipal bonds (pollution revenue bonds)?

Answer: None. See response to question 6.

11. About how many points below the market is the interest charge on this form of financing? Do you intend to finance future pollution control investments in the same manner?

Answer: Not applicable. See response to question 6.

12. If the 1971 NSPS replaced the current standards for new power plants, what type of control method would you use and where would you buy your coal? Why?

Answer: TVA has no plants subject to NSPS. If TVA were building a new coal-fired plant at this time, limestone scrubbers would probably be selected as the SO_2 control method, whether the 1971 NSPS replaced the current standards or not. The coal would probably be supplied from the interior basin. Based on our present assessments, this would provide the most economical method of compliance.

13. What are the projected revenue requirements of your system for each year with S. 1706, versus revenue requirements for the same years without S. 1706?

Answer:

Year	Projected Revenue* Requirements With S. 1706 ($\$10^6$)		Projected Revenue Requirements Without S. 1706 ($\$10^6$)	
	High-Load Forecast	Low-Load Forecast	High-Load Forecast	Low-Load Forecast
1992	13,498	10,287	12,486	9,742
1993	15,120	10,857	14,054	10,285
1994	17,133	11,706	16,003	11,103
1995	19,203	12,923	18,006	12,287

*Total compliance cost including amortization of costs escalated at 10 percent per year from 1982 to 1992. After 1992, only operation and maintenance costs are escalated (10 percent).

14. Please provide growth rate assumptions to years 1990 and 2000 and your current and projected reserve margins.

Answer: TVA projects future load growth using a wide range of assumptions. From these assumptions, a low-load growth estimate is derived which has a 90-percent probability of being exceeded; a medium load growth estimate with a 50-percent probability of being exceeded; and a high-load growth estimate with a 10-percent probability of being exceeded. Our projected load growth estimates using the FY 1982 forecast are as follows:

	1981-1990	1990-2000
Low-load growth	.4% per year	.2% per year
Medium-load growth	1.3% per year	1.9% per year
High-load growth	2.2% per year	2.7% per year

TVA's current and projected reserve margin will be provided later.

15. How much and from what markets do you intend to purchase coal under a reduction program similar to S. 1706?

Answer: TVA would use scrubbers as the primary method of compliance with a reduction program similar to S. 1706. Consequently, no major changes in TVA's existing coal markets are projected. TVA's coal purchases between 1983 and 1995 are expected to range between 20 and 35 million tons per year depending on the power system load growth. However, based on a rough analysis, the purchase of low-sulfur coal could increase by 3 to 7 million tons per year to comply with S. 1706.

16. Provide information on the age, capacity, sulphur and NO_x emission rates, and expected retirement dates for each plant in your system with and without a reduction program similar to S. 1706. Given current replacement costs please explain any differences between the two dates as fully as possible.

Answer: The attached Table 1 shows capacity, the year of commercial operation of the last unit, NO_x emissions rate, and SO2 emissions, with and without a reduction program similar to S. 1706 for each of the TVA fossil-fired plants.

TVA has not scheduled any existing plants for retirement. "Mothballing" of some of the older units is expected however.

17. (a) Please provide a detailed breakdown of scrubber costs, including whether your estimates include scrubber spares.

(b) Provide information on the reduction percentage, age and reduction in operating efficiencies from currently operating scrubbers in your system.

Answer: (a.) TVA did not calculate any detailed breakdown of scrubber costs. As indicated earlier the capital cost for scrubbers was assumed as \$155/kW which does not include scrubber spares etc. A capacity penalty of 4 percent and a heat rate penalty of 4.4 percent was assumed. A cost of roughly \$0.15/M Btu (1982 Dollars) was used as the composite value of these penalties. TVA has prepared reports on the average cost of scrubbers and scrubber components. These reports will be provided later.

(b.) To date TVA's operating experience with bull-made scrubbers is limited to a single scrubber which has been in operation since 1977 on the Widows Creek plant's 550,000 kW unit 8. The unit 8 scrubber uses ground limestone absorbent and has typically operated with good success at SO_2 removal efficiencies in the range of 80 to 90 percent. Due to unusually long unit outages caused by boiler and turbogenerator problems at unit 8 during the 1977-1980 period, TVA was able to make modifications and maintain high availabilities and performance of the scrubber unit. Attempting to correlate age and change in operating efficiency is therefore not appropriate. In addition, the scrubber was originally intended as a research and development project in the early 1970's but has been modified to conform to current technology as part of TVA's SO_2 compliance program.

18. Please indicate what percentage of the coal burned by your system is washed and why it is washed (environment, corrosion prevention, etc.). What percentage of sulfur is removed?

Answer: Approximately 65 percent of the coal burned by TVA is washed, and approximately 10 percent is blended (i.e., a mixture of washed and unwashed coal). Coal is washed primarily to meet SO_2 emission limitations and in a few cases to reduce ash content. We estimate that on the order of 20 to 25 percent of the sulfur is removed by washing.

19. How much of your coal comes from mines outside the S. 1706 arms region?

Answer: None of the coal burned by TVA comes from outside the S. 1706 ARMS region.

20. Provide your analysis of the use of NO_x controls as a partial or complete alternative reduction strategy.

Answer: TVA did not consider the use of NO_x control as part of its reduction strategy in computing the cost effects of S. 1706 on the TVA system.

21. What would be the impact, on projected reduction costs, of allowing CWIP for pollution control equipment into your current rate base?

Answer: Not applicable.

22. Provide any documentation on reliability, or effectiveness and cost of NO_x control devices.

Answer: Later

23. Would the imposition of mid-term emissions (e.g., 5 million tons at 5 years if the total goal is 10 million tons in 10 years) reductions increase or decrease long-term reduction costs? Would it alter your choice of reduction methods?

Answer: Later

24. If the Congress decides that a 50- or 75 percent reduction in SO_2/NO_x emissions is a necessary goal for this country, what is your view of the most efficient means of achieving it?

Answer: Later

25. Please state what percentage of your electricity is either received from or shipped to other utilities. Please also state what percentage of your power is generated at facilities which are owned or operated with other utilities.

Answer: Later

In addition to the written questions, TVA was requested at the meeting to provide the following information:

A. What is the detailed cost breakdown of compliance measures needed to meet existing SO_2 and particulate emission requirements? (Preferably in a plant-by-plant format.)

Answer: Table 2 [to be provided later] shows a detailed cost breakdown of estimated capital costs and annual costs for fiscal year (FY) 1983 for compliance measures under the consent decree. The annual costs for subsequent years will vary depending upon the use of coal-fired generating plants and supply of load demand from nuclear plants.

B. What impact has compliance with existing requirements had on rates?

Answer: In the early 1980's, when TVA's compliance program will be completed, costs will amount to about 8 percent of TVA's total revenue requirements (i.e., rates will be increased by about 8 percent). By the early 1990's, the impact would be reduced as additional nuclear units come online and coal-fired generation becomes a smaller fraction of the total rate base.

C. What has TVA's experience been with actual time required to come into compliance for each control technology, particularly the time required for planning and design, construction, and check out prior to operation for each alternative; scrubber, coal washing facility, bag house, etc.)

Answer: See attached Charts C-1, C-2.

D. What levels of emissions did TVA assume to be required under S. 1706 by state in which a plant is located.

Answer: Required emissions under S. 1706 (permissible levels after reductions are made) on a State basis for TVA plants are:

Kentucky - 115,200 tons
Alabama - 83,900 tons
Tennessee - 321,300 tons

E. When would TVA have to initiate planning and construction of compliance measures if S. 1706 were to be passed and signed into law now? (When would commitment of significant capital expenditures begin?)

Answer: Later

F. Can TVA identify specific break points in levels of reduction required at which incremental costs for further reduction escalate dramatically?

Answer: Later

G. What are the capabilities for sulfur reductions through coal washing only, i.e., for coals used by TVA how may pounds of reduction can be achieved through washing giving "pre" and "post" washing sulfur contents.

Answer: Approximately 65 percent of the coal presently utilized on the TVA system is already washed and roughly 10 percent is blended (i.e., a variable mixture of washed and unwashed coal). Only 25 percent is raw, unwashed coal. Of this raw coal, more than 90 percent either has a sulfur content of less than 2 percent or is burned in scrubbers. It is estimated that TVA's emissions would be reduced by only 24,000 tons or less than 2 percent if this coal were washed.

Table 1

TVA FOSSIL-FIRED PLANTS
AIR QUALITY DATA WITH AND WITHOUT S 1706

Plant	Capacity (MW)	Commercial Operation (Last Unit)	NO_x Emissions ($Lbs/10^6$ Btu)	SO_2 Emissions Without S 1706	($Lbs/10^6$ Btu) With S 1706
Allen	990	1959	2.4	4.0	1.2
Bull Run	950	1967	0.8	4.0	1.2
Colbert 1-4	870	1955	0.8	4.0	1.2
5	550	1965			
Cumberland	2,600	1973	0.8	5.0	0.75
Gallatin	1,255	1959	0.8	5.0	1.2
Johnsonville	1,485	1959	0.8	3.4	3.4
John Sevier	847	1957	0.8	4.0	1.2
Kingston	1,723	1955	0.8	2.8	1.2
Paradise 1-2	1,408	1963	2.4	3.1	0.75
3	1,150	1970			
Shawnee	1,750	1956	0.8	1.2	1.2
Watts Bar*	240	1945	-	-	-
Widows Creek 1-6	853	1954	0.8	1.2	1.2
7-8	1,125	1965			

*Assumed to be "mothballed" by 1992.

Power Projects Staff
6/14/82

Table 2

CONSENT DECREE COMPLIANCE COSTS IN 1983
TVA COAL-FIRED PLANTS

Plant	Type of Equipment	Estimated Capital Cost	Estimated Annual Cost (1982 dollars)
Allen	Medium Sulfur Coal	$ -	$ 5
Colbert	Medium Sulfur Coal	-	8
Cumberland	Coal-washing facility	53	
	Precipitators	120	
	Scrubbers (cancelled)	19	
	Total Cumberland	192	49
Gallatin	Medium Sulfur Coal and precipitators	43	23
Johnsonville	Medium Sulfur Coal, Stacks and precipitators upgrade	69	50
Kingston	Low-Sulfur Coal		12
Paradise	Coal-washing facility	115	
	Scrubbers for Units 1&2	151	
	Precipitators for unit 3	30	
	Total Paradise	296	87
Shawnee	Low Sulfur Coal and Baghouses	76	56
Watts Bar	Medium Sulfur Coal		2
Widows Creek	Low Sulfur Coal (units 1-6) Scrubbers and Medium Sulfur Coal (units 7)	48	
Total		$724	$334

a. Does not include capital cost of land and other facilities for sludge disposal beyond 1983.

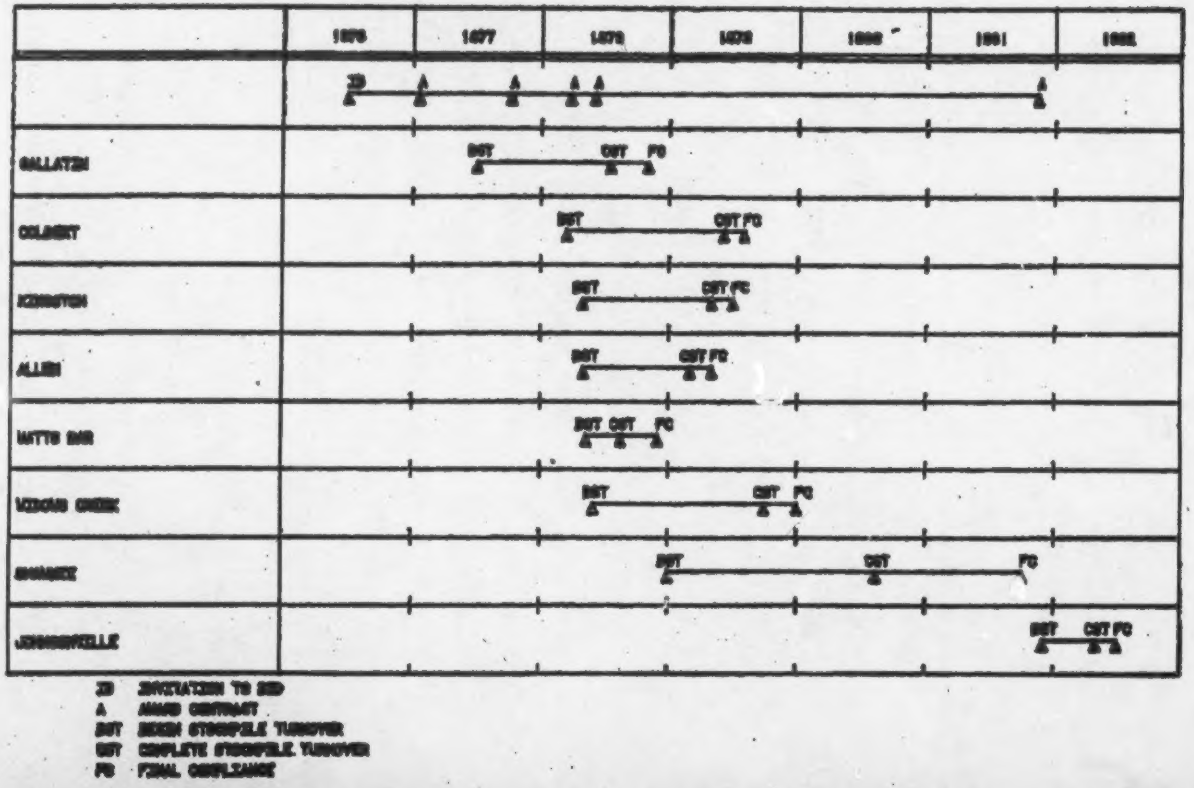
b. Discount rate assumed as 12 percent.

Power Projects Staff - October 6, 1981

Rec. 6-16-82
4:00pm

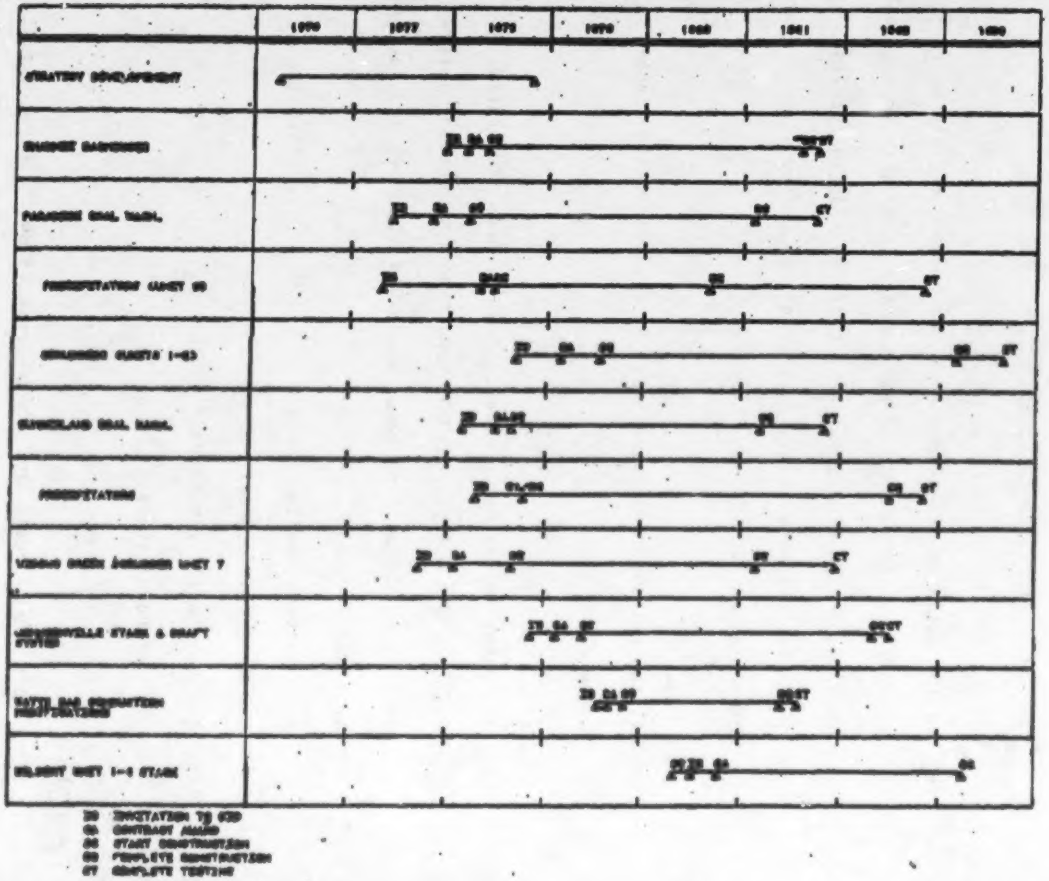
C-1

COAL STRATEGIES FOR CONSENT DECREE PLANTS



C-2

AIR QUALITY PROJECTS



Additional Responses to Written Questions

4. (a) If the emission reductions required by an acid rain control program were 80 percent of the tonnage assumed in your calculations, by how much would your costs be reduced (provide your best estimate, e.g., 10 percent, 25 percent, 50 percent reduction in cost)?

(b) If the emission reductions were 60 percent of the tonnage assumed?

(c) All other things being equal, if S. 1706 as now drafted required a 5 million ton SO_2 reduction from current levels rather than 10 million tons, how would it affect key factors such as:

--total capital costs

--\$/ton removed

--electricity rates

--annual costs.

Answer:

(a) TVA's annual costs would be reduced by about 30 percent if the acid rain control program required 80 percent of the tonnage required by S. 1706.

(b) TVA's annual costs would be reduced by about 50 percent if the acid rain control program required 60 percent of the tonnage required by S. 1706.

(c) We assume that a 5 million ton reduction means that an acid rain control program would require only 50 percent of the reduction in tonnage required of TVA under S. 1706. For this case, TVA's costs (in 1982 dollars) are roughly estimated to be:

Capital Cost	$400 million
$/ton removed	$500/ton
Percent Increase in 1992 rates	3 percent
Annual costs	$135 million

The above costs were roughly estimated using TVA's detailed analysis of the Mitchell bill as a guide. There could be areas where costs could be reduced if an optimization study were performed. The costs given above are based on TVA's high-load forecast. Similar percentage reductions would be expected for the low-load.

20. Provide your analysis of the use of NO_x controls as a partial or complete alternative reduction strategy.

Answer:

TVA has limited experience in the area of retrofitting NO_x controls to existing powerplants. Attempts were made at TVA's Widows Creek Steam Plant to test biased firing conditions as a control measure for NO_x. Although NO_x emissions were reduced, it was found that (1) carbon levels in the particulate increased (expected to affect precipitator efficiency), (2) boiler efficiencies were reduced, and (3) severe corrosive atmospheres developed in the boiler. TVA did not consider the use of NO_x control as a part of the control strategies assumed for purposes of meeting S. 1706.

22. Provide any documentation on reliability, or effectiveness and cost of NO_x control devices.

Answer:

Sent under separate cover are reports which address the technology and estimated cost of NO control devices. With the exception of the report discussing TVA's experience with retrofitting NO_x control at Widows Creek Steam Plant, all reports deal with NO_x control being included as a part of a new plant design. The documents do not reflect retrofit cases or the problems associated with retrofitted NO_x control.

25. Please state what percentage of your electricity is either received from or shipped to other utilities. Please also state what percentage of your power is generated at facilities which are owned or operated with other utilities.

Answer:

In fiscal year 1981, TVA received approximately 13 percent of the electricity it supplied from other utilities. Approximately 10 percent of the power that TVA supplied was sent to other utilities. None of the power TVA supplied was generated at coal-fired facilities which are owned or operated with other utilities.

13. Additional response and clarification of projected revenue requirements with and without S. 1706 - Question No. 13.

Answer:

The low-load forecast revenue requirements with S. 1706 assume that a compliance scheme is implemented which is based on the low-load forecast. This in essence restricts the generation of the coal-fired systems to the levels projected under the low-load forecast. Compliance with S. 1706 could not be maintained if higher loads than those forecast for the low growth developed or if generation from nuclear and hydro sources is not as estimated.

Following are revenue requirements under the low-load forecast which would be required if a compliance scheme were implemented which would provide flexibility to meet S. 1706 under both the high- and low-load forecasts.

Year	Low-Load Forecast Projected Revenue Requirement Without S. 1706 ($10^6\ \$$)	Low-Load Forecast Projected Revenue Requirements With Flexible Compliance Scheme To Meet S. 1706 ($10^6\ \$$)
1992	9,742	10,623
1993	10,285	11,209
1994	11,103	12,074
1995	12,287	13,310

9. Where do you purchase your coal and what is its delivered price? What is the method and cost of transportation, in distance hauled?

TVA purchases approximately 50 percent of its coal from the Interior Basin area and about 50 percent from the Appalachian region. In FY 81, TVA paid an average cost of about $40 per ton for the coal it received. On a plant specific basis, average FY 81 costs ranged from $23 per ton to $51 per ton received. In most cases, coal suppliers are responsible for transportation when coal is sent by either truck or barge. The distance that coal is barged varies from only a few miles for locally available coal to over 1000 miles for coal barged from Ohio to Alabama. Generally, TVA pays rail transportation, and rail costs currently range from roughly $4.50/ton to about $9.70/ton. Distance that coal is hauled by train ranges from about 50 miles to 275 miles.

23. Would the imposition of mid term emissions (e.g., 5 million tons at 5 years if the total goal is 10 million tons in 10 years) reductions increase or decrease long-term reduction costs? Would it alter your choice of reduction methods.

It is difficult to estimate the effect a mid term emission reduction would have on long-term reduction cost and methods. We believe that costs would be greater, however. To meet a mid term limit would require TVA to switch to low-sulfur coal at various plants. The amount of low-sulfur coal required would depend on the amount of load growth experienced. Since lower sulfur coal would be the only practical alternative, demand for this coal would increase and prices would probably escalate. Depending on the market situation (i.e., the bargaining strength of low-sulfur coal suppliers), long-term coal contracts could be required by coal suppliers. Consequently, TVA could end up burning higher cost low-sulfur coal at plants that would have otherwise been retrofitted with scrubbers under the most economical long-term compliance plan which would have been used in absence of a mid term emissions reduction requirement.

24. If the Congress decides that a 50- or 75-percent reduction in SO_2/NO_x emissions is a necessary goal for this country, what is your view of the most efficient means of achieving it?

To achieve a major reduction in power supplier SO_2/NO_x emissions in the most efficient manner would require that a variety of control strategies be evaluated by each power supplier for each of its power plants. Many methods of reducing emissions are available--purchasing lower sulfur coal, washing coal, scrubbers, least-emissions dispatching, power plant retirements or derating, and others. The magnitude of the emissions reduction and the corresponding costs are both functions of many factors. These would include such things as plant location, the nature of existing coal contracts, plant age and projected future use, and technical considerations such as the ability to burn low-sulfur coal or space and equipment interferences affecting scrubber retrofits. Each one of these factors plus others which would be identified as studies are undertaken must be completely evaluated on a plant specific basis and then a power system basis before the most efficient method for reducing emissions could be determined. Accordingly, it is not possible to generalize about the most efficient means of achieving a large reduction in emissions.

Additional Verbal Questions

What is the percent completion of the nuclear units that have been deferred by TVA?

Hartsville Nuclear Plant
Units A1 - 42 percent
Unit B1 - 17 percent

Unit A2 - 32 percent
Unit B2 - 7 percent

Phipps Bend Nuclear Plant
Units 1 - 27 percent
Unit 2 - 5 percent

Yellow Creek Nuclear Plant
Unit 1 - 33 percent
Unit 2 - 3 percent

(Completion percentages are as of December 31, 1981; based on work completed as compared to total work estimated)

Table 1

AIR POLLUTION CONTROL COST IN 1983
TVA COAL-FIRED PLANTS
(Millions of Dollars)

Plant	Type of Equipment	Estimated Capital Cost	Estimated Annual Cost (1982 dollars)
Allen	Precipitators	$ 10	$ 6
Bull Run	Precipitators	33	4
Colbert	Precipitators	22	
	Stacks and duct	15	14
	Total Colbert	37	
Cumberland	Coal-washing facility	53	
	Precipitators	133	
	Scrubbers (cancelled)	19	
	Total Cumberland	205	50
Gallatin	Precipitators	49	24
John Sevier	Precipitators	12	2
Johnsonville	Precipitators	27	
	Stacks and precipitators upgrade	69	
	Total Johnsonville	96	54
Kingston	Precipitators and stacks	71	22
Paradise	Coal-washing facility	115	
	Scrubbers	151	
	Precipitators	37	
	Total Paradise	303	88
Shawnee	Precipitators	9	
	Baghouses	76	
	Tall stacks	26	
	Total Shawnee	111	61
Watts Bar	Precipitators	2	2
Widows Creek	Precipitators and stacks	55	
	Scrubbers	98	
	Total Widows Creek	153	49
Total		$1,082	$376

a. Does not include capital cost of land and other facilities for sludge disposal beyond 1983.

b. Discount rate assumed as 12 percent.

* All plants with the exception of Bull Run and John Sevier were subject to the requirements of the consent decrees. Costs shown are for all air pollution controls and do not distinquish consent decree costs only.

Power Projects Staff - 10/6/81